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LABORATORY TESTING OF PORTLAND CEMENT CONCRETE PATCH MATERIAL, MODIFIED TO REDUCE OR ELIMINATE SHRINKAGE

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16. Abstract

This study was initiated in response to the development of early distresses in the patch material of a dowel bar retrofit (DBR) project located in Marshfield, Wisconsin. Primarily, the slightly modified Mn/DOT 3U18 patch material used on WisDOT's DBR project exhibited microcracking and debonding from the sidewalls of the DBR slots. These distresses are a result of shrinkage. Since the Mn/DOT 3U18 patch material is significantly less expensive than other proprietary rapid setting patch materials and its components are readily available, WisDOT deemed it worthwhile to seek an inexpensive way to improve the performance of the material.

Three main concepts were identified as possible techniques for reducing shrinkage in the Mn/DOT 3U18 patch material: expansive cements or additives, shrinkage reducing admixtures, and internal curing through the use of saturated lightweight fine aggregate. The 11 products used to modify the Mn/DOT 3U18 patch material in this study were Type K cement, Komponent, Denka CSA #20 (50.56 lb/yd^3 or 30 kg/m^3), Denka CSA #20 (42.14 lb/yd^3 or 25 kg/m^3), Denka CSA 100R (50.56 lb/yd^3 or 30 kg/m^3), Denka CSA 100R (42.14 lb/yd^3 or 25 kg/m^3), Peramin SRA330, Eclipse Plus, Tetraguard AS20, Solite, and Hydrocure. Sealtight 2255-White, a poly-alphamethylstyrene-based concrete curing compound, was also evaluated for its effectiveness in preventing water loss from the surface of the patch material in comparison with Sealtight 1600-White, a water-based, wax-based curing compound.

After extensive laboratory testing, it was found that only the Denka CSA #20 product, at a 50.56 lb/yd^3 (30 kg/m^3) dosage rate, and the Tetraguard AS20 were able to successfully reduce shrinkage in the Mn/DOT 3U18 patch material without negatively impacting other vital properties required for concrete patch materials. Patch material containing Denka CSA #20 is approximately 10 percent less expensive than patch material containing Tetraguard AS20, but both products provide significant cost savings when compared to some proprietary rapid setting patch materials. It was also found that the Sealtight 2255-White showed 69% less water loss than the Sealtight 1600-White, but is also three times more expensive than the Sealtight 1600-White. Both curing compounds, however, met WisDOT specifications for both water retention and reflectance.

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1.0 BACKGROUND

In the summer of 2001, the Wisconsin Department of Transportation (WisDOT) rehabilitated a section of State Trunk Highway (STH) 13 in Wood County, Wisconsin, using the dowel bar retrofit (DBR) technique (Bischoff & Toepel, 2001). This DBR project was the test site for a research study evaluating the performances of six different high performance concrete (HPC) patch materials. Samples of all six patch materials from the STH 13 DBR project were sent to the WisDOT Materials Laboratory for testing. Of the six patch materials, only the following three met all of WisDOT's requirements for rapid set concrete patch materials:

- Tamms Speed Crete 2028 at 100% Extension[1],
- Tamms Speed Crete 2028 at 80% Extension[1], and
- Mn/DOT 3U18[2].

As shown in Table 1 on the following page, WisDOT's requirements for rapid setting concrete patch materials used in DBR projects have been modified recently. At the time the STH 13 DBR was constructed, rapid set concrete patch materials had to meet the standard requirements established for inclusion on the WisDOT Approved Products List.[3] In 2004, WisDOT created a warranty specification (Pavement Dowel Bars Retrofit Warranted, Item 416.0623.S) for the DBR technique with slightly different requirements for rapid setting concrete patch materials. The DBR warranty specification also mandates the use of a curing agent that is a resin of 100 percent poly-alphamethylstyrene.

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[1] The Tamms Speed Crete 2028 is a proprietary mortar material. The percentage of extension refers to the weight of coarse aggregate (3/8-inch pea gravel) added, in relation to the weight of mortar (bagged cement and sand blend) being used.

[2] Mn/DOT 3U18 refers to a modified version of the Minnesota Department of Transportation's Specification 3U18 concrete (modified with Type III cement, with a total alkali as Sodium Oxide content no greater than 0.60 percent, instead of Type I cement).

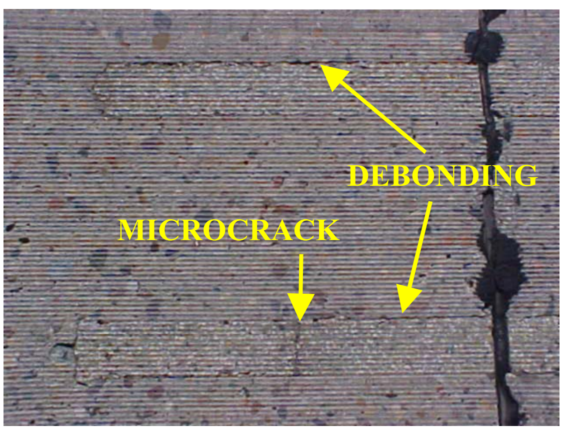
[3] Testing of the rapid set concrete patch materials is conducted by the National Transportation Product Evaluation Program (NTPEP), sponsored by the American Association of State Highway Transportation Officials (AASHTO).

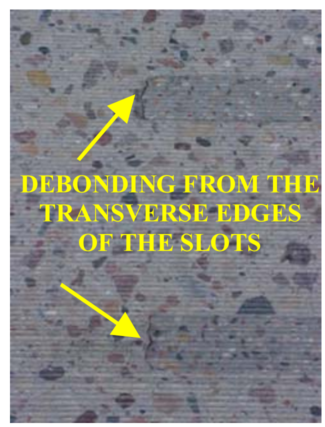
Table 1. Rapid Setting Concrete Patch Material Requirements

TESTED PROPERTY	ASTM TEST PROCEDURE	WisDOT REQUIREMENT 2001 WisDOT APPROVED PRODUCTS LIST	WisDOT REQUIREMENT DBR WARRANTY SPECIFICATION ITEM 416.0623.S (2004)
Compressive Strength	ASTM C 39	2000 psi @ 2 hours 4000 psi @ 7 days	3000 psi @ 3 hours
Freeze/Thaw Durability (w/ 5% sodium chloride solution)	ASTM C 666	minimum durability factor of 90% after 300 cycles (using Procedure B)	minimum durability factor of 90% after 300 cycles (using Procedure A)
Initial Time of Set	ASTM C 266	minimum of 15 minutes	no requirement
Linear Shrinkage	ASTM C 531	maximum of 0.100% @ 3 days	maximum of 0.100% @ 3 days

Although the three aforementioned patch materials met WisDOT's requirements in 2001, within one year they all showed signs of early distress on STH 13. All of the test sections constructed with either Tamms Speed Crete 2028 or Mn/DOT 3U18 mix exhibited microcracking and/or debonding, most likely caused by shrinkage (see Figure 1 below). The distresses observed in the Mn/DOT 3U18 test sections were the most severe.

Figure 1. Patch Material Distress on STH 13





The Mn/DOT 3U18 test sections exhibited both debonding and microcracking in some areas (left). Less severe debonding of the patch material, from the transverse edges of the dowel bar slots, was observed in the Tamms Speed Crete 2028 test sections (right).

Since the Mn/DOT 3U18 patch material was significantly less expensive than the Tamms Speed Crete 2028 (approximately 1/10th the cost) and its components were readily available, WisDOT deemed it worthwhile to seek an inexpensive way to improve the performance of the material. This study tested and evaluated various modified Mn/DOT 3U18 mixes in an attempt to prevent patch material shrinkage, and any associated cracking and debonding. The objective of this research was to find a cost-effective method of modifying the Mn/DOT

3U18 patch material so that it performed better than the standard Mn/DOT 3U18 (i.e. less shrinkage, cracking, and debonding) in a DBR application.

2.0 INTRODUCTION

As previously stated, the cracking and debonding that developed on STH 13 was caused by shrinkage of the patch material. To provide its high strength, the Mn/DOT 3U18 patch material sacrifices its water content, thus reducing the water-to-cement ratio (w/c). As time passes after concrete is placed, the surface water and some of the water contained within the concrete begins to evaporate.[4] This loss of water results in plastic, drying, and chemical shrinkage. When the w/c of a concrete mix is below 0.42, as in high performance concrete (HPC), the concrete undergoes another form of shrinkage known as autogenous shrinkage.

Autogenous shrinkage is caused by an internal drying of the concrete. For concrete to achieve its ideal strength, the individual cement particles must become fully hydrated so that they can achieve a tight bond with the coarse and fine aggregate in the mix. As soon as the concrete components are mixed together, the cement begins to absorb water from the mix to begin hydration. However, the low w/c of HPC often does not supply enough water to completely hydrate all of the cement. The absorption by the cement of all the free water within the concrete and the demand for more results in negative capillary pressure, causing the concrete to contract and shrink in volume. This shrinkage induces tensile stresses within the patch material, causing it to debond from the existing concrete around it, or causing the concrete patch material itself to crack.

3.0 SHRINKAGE REDUCTION CONCEPTS

Three main concepts were identified as possible techniques for reducing shrinkage in the Mn/DOT 3U18 patch material: expansive cements or additives, shrinkage reducing admixtures, and internal curing through the use of saturated lightweight fine aggregate. In

[4] It should be noted that no external source of water is provided to the patch material during the curing process on a DBR project. On STH 13, the application of a water-based, wax-based concrete curing compound (Sealtight 1600, manufactured by W.R. Meadows) was the only curing technique the patch materials received.

addition to these techniques, which all modified the Mn/DOT 3U18 patch material, this study also evaluated a poly-alphamethylstyrene-based concrete curing compound and compared it to a water-based, wax-based curing compound for its effectiveness in preventing a loss of water from the patch material after it has been placed.

3.1 Expansive Cement

There are a few variations of expansive cement available that meet the requirements of ASTM C 845 (Standard Specification for Expansive Hydraulic Cement); however, only the Type K variation is available in the United States (Portland Cement Association, n.d.). Type K cement is composed of Portland cement, anhydrous tetracalcium trialuminosulfate, calcium sulfate, and uncombined calcium oxide (lime) (Portland Cement Association, n.d.). When the cement is mixed with water, the chemical reaction between the hydrating aluminum-rich Portland cement and the calcium sulfate eventually leads to the formation of ettringite crystals. Ettringite has a larger volume than its components and causes the concrete to expand, thus compensating for the shrinkage the concrete will undergo. Eventually, the concrete will achieve a maximum expansion and it will then begin shrinking at the same rate as it would if regular Portland cement was used, for a net volume change near zero. This expansion and delayed shrinkage reduces or, in some cases, altogether eliminates shrinkage cracking.

Many states use Type K cement in concrete bridge deck construction to reduce shrinkage cracking, thereby preventing both premature deck deterioration and reduced durability. WisDOT has used Type K cement on several bridge decks within the last few years and it has shown good performance overall. However, due to the current high cost of the Type K cement, WisDOT discontinued its use in bridge deck applications.

3.2 Expansive Additive

Commercially available, non-gas producing expansive admixtures are either lime or calcium sulfoaluminate-based (Standards Association of Australia, 1977). Lime-based expansive admixtures were not included in this study, due to poor performance results in previous testing conducted by Mailvaganam, Nunes, and Bhagrath (1993). Calcium sulfoaluminate-based admixtures, which are included in this study, work based on the same principles as expansive cements, but the powdered admixture allows the dosage of calcium sulfoaluminate (CSA), which is required for the formation of the ettringite, to be adjusted in order to achieve the desired amount of expansion. Due to time and material constraints, only three CSA-based additives were selected for evaluation in this study: Denka CSA #20, Denka CSA 100R, and Komponent.

Denka Corporation manufactures a variety of CSA-based expansive additives for cement, but the Denka CSA #20 and Denka CSA 100R products are most applicable to highway construction projects. Both products claim to reduce shrinkage and the associated cracking. Denka CSA #20 is a suitable product for multiple applications, including concrete pavement. Denka CSA 100R is primarily recommended for warm weather construction projects, as it is composed of Denka CSA #20 with an added agent to reduce the heat of hydration.

CTS Cement Manufacturing Corporation also manufactures a CSA-based expansive additive. This manufacturer claims that their additive, called Komponent, when added to regular Portland cement (approximately 100 lb/yd^3), produces a mixture similar to Type K cement.

3.3 Shrinkage Reducing Admixture

Capillary pressure is the primary mechanism contributing to concrete shrinkage. The water loss occurring in the concrete results in the formation of menisci in the capillary pores. An internal negative pressure develops as the surface tension of the water pulls in on the walls of the pores and causes an overall compressive force on the skeleton of the concrete. The liquid shrinkage reducing admixtures (SRA's) included in this research study propose to lessen concrete shrinkage by acting chemically to reduce the surface tension of the water and therefore lower the capillary pressure.

Three SRA's, frequently referenced in related literature, were included in this study: Eclipse Plus, manufactured by Grace Construction Products; Peramin SRA330, manufactured by Perstorp Polyols, Inc.; and Tetraguard AS20, manufactured by Degussa Admixtures, Inc., formerly Master Builders Technologies. Several other SRA's are also on the market, but due to time and material constraints they were not evaluated in this study.

3.4 Internal Curing Using Saturated Lightweight Fine Aggregate

The technique of internally curing high performance concrete (HPC), originally proposed in 1991 by Philleo and later refined by Weber and Reinhardt in 1995; Bentur, Igarashi, and Kovler in 1999; and Bentz and Snyder in 1999, also shows promise of reducing shrinkage. To cure concrete internally, this technique replaces a portion of the fine aggregate in the mix with an equal volume of saturated lightweight fine aggregate (LWFA). LWFA has a higher absorption capacity than typical fine aggregate and is therefore able to store more water. Once the hydration of the cement particles uses up the free water in the concrete mix, the water is drawn out of the pores of the LWFA to continue the curing process. The researchers claim that this extra supply of water allows the cement particles to achieve complete hydration and prevents shrinkage altogether.

LWFA composed of expanded slate and shale (see Figure 2 on the following page) was selected for this study based on research conducted by Roberts (2002). This type of LWFA is manufactured using a rotary kiln process and the unit weight varies between 45-62 lb/ft^3 loose bulk density, about half the weight of typical sand and stone (Solite, 2003). Expanded slate and shale LWFA from Solite Corporation (Solite) and Northeast Solite (Hydrocure) are evaluated in this study.

The technique of using saturated LWFA to internally cure HPC has not yet been tested in concrete pavement applications. However, lightweight concrete made from expanded slate and shale has been used for years in bridge decks all over the world. Bridge decks composed of lightweight aggregate in both Maryland and New York have lasted more than 30 years, exposed to numerous freeze/thaw cycles and applications of deicing salts (Holm, Bremner, & Newman, 1984).

Figure 2. Expanded Slate and Shale Lightweight Fine Aggregate

The expanded slate and shale lightweight fine aggregate, as shown above, replaces a portion of the fine aggregate (i.e. sand) to internally cure the concrete.

3.5 Poly-Alphamethylstyrene-Based Concrete Curing Compound

Preventing the evaporation of water from concrete is an important element in minimizing shrinkage. A concrete curing compound with high water retention is extremely important; especially for a concrete mix with a low w/c. WisDOT restricts the water loss for concrete curing compounds to no more than 0.11 lb/ft^2 (0.55 kg/m^2) in 72 hours.[5] The concrete curing compound used on the STH 13 dowel bar retrofit (Sealtight 1600-White, manufactured by W.R. Meadows) typically allows a water loss of approximately 0.06 lb/ft^2 (0.30 kg/m^2) in 72 hours when tested by the WisDOT Materials Testing Laboratory. The manufacturer of Sealtight 2255-White, the poly-alphamethylstyrene-based concrete curing compound selected for this study, states that Sealtight 2255-White allows even less water loss, with a typical water loss of 0.04 lb/ft^2 (0.21 kg/m^2) in 72 hours (W.R. Meadows, 2002).

[5] WisDOT Standard Specifications for Highway and Structure Construction, 2004 Edition, Section 415.2.4 (in conformance with AASHTO M 148).

Performance results reported by the California Department of Transportation (Caltrans) and the Minnesota Department of Transportation (Mn/DOT) indicate that concrete curing compounds with resin composed of 100 percent poly-alphamethylstyrene show excellent water retention (Vandenbossche, 1999). In fact, largely due to Mn/DOT's experience, WisDOT's DBR warranty specification requires the use of a concrete curing compound that is a resin of 100 percent poly-alphamethylstyrene with a water loss of no more than 0.08 lb/ft^2 (0.40 kg/m^2) in 72 hours.

4.0 PROJECT OVERVIEW

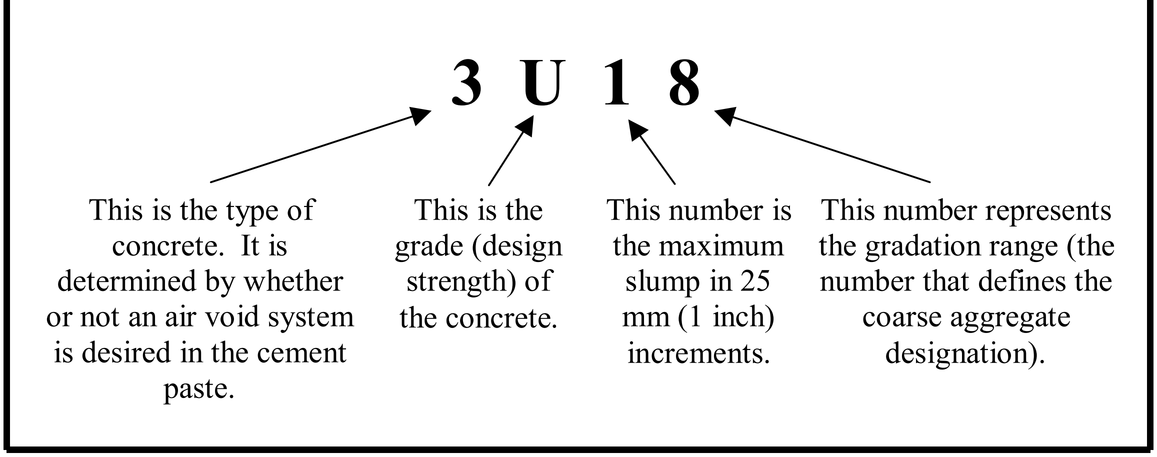
This research study involved laboratory testing only; no field testing was conducted. All tests were performed in an AASHTO accredited lab under the supervision of WisDOT's chief concrete engineer, Jim Parry.

4.1 Standard Mn/DOT 3U18 Concrete Mix

The control mix for this research study was based on the design for the Mn/DOT 3U18 concrete mix. Mn/DOT uses a mix numbering system to classify concrete. The first digit designates the type of concrete (i.e. whether or not it includes an air entrainer), the second digit designates the grade of concrete (i.e. its design strength), the third digit designates the upper slump limit of the concrete, and the fourth digit designates the gradation range of the aggregate.

As shown in Figure 3 on the following page, 3U18 concrete is designated as Type 3 concrete (not to be confused with Type 3 cement), which means it contains an approved air entraining admixture to produce a specified air content of 4 to 7 percent. It is classified as Grade U concrete, so it has an anticipated compressive strength of 5600 psi at 28 days. The concrete is allowed a maximum slump of 1 inch and it is composed of coarse aggregate from Range 8. This aggregate gradation consists of the CA-80 coarse aggregate, which represents coarse aggregate sizes smaller than 3/8-inch. Although not designated in the mix numbering system, fine aggregate is also included in the 3U18 mix.

Figure 3. Mn/DOT's Concrete Mix Numbering System



4.2 Mn/DOT 3U18 Patch Material (Control Mix For This Study)

Mn/DOT's 3U18 concrete mix design was revised for this study by substituting Type III cement for Type I cement to create a more rapid setting concrete. Also, since different admixtures can have varying effects on the slump of the patch material, the modified Mn/DOT 3U18 patch materials were not held to the same slump requirements. Instead, it was determined that each modified patch material would be mixed with the same w/c. The Mn/DOT 3U18 control patch material was mixed first and it was found that the lowest water content the patch material could be mixed at and still be workable, to provide good consolidation around the dowel bar, yielded a w/c of 0.395. This produced a slump of 2¼ inches for the Mn/DOT 3U18 control. All of the modified patch materials, with the exception of the sample containing Type K cement, were mixed with a w/c of 0.395. On the advice of the manufacturer, the sample containing Type K cement was mixed with a w/c of 0.42, the lowest w/c at which the expansive properties of the Type K cement can be effective.

4.3 Modified Mn/DOT 3U18 Patch Materials

Table 2 on the following page shows the 12 patch materials evaluated in this study. The Mn/DOT 3U18 patch material (Sample 1) was used as the control for comparisons with the modified Mn/DOT 3U18 patch materials (Samples 2-12). See Appendixes A and B for a detailed description of the patch material mix designs.

4.4 Concrete Curing Compounds

Table 2 also shows the two concrete curing compounds evaluated in this study. The Sealtight 1600 curing compound was used as the control for comparisons with the Sealtight 2255 curing compound.

Table 2. Products Evaluated in This Study

SAMPLE NUMBER	MODIFIED PATCH MATERIAL DESCRIPTIONS	SHRINKAGE REDUCTION METHOD
1	Mn/DOT 3U18 **(CONTROL)**	None
2	Mn/DOT 3U18 w/ Type K Cement	Expansive Cement
3	Mn/DOT 3U18 w/ Komponent	Expansive Additive
4	Mn/DOT 3U18 w/ Denka #20 (50.56 lb/yd^3 or 30 kg/m^3)	Expansive Additive
5	Mn/DOT 3U18 w/ Denka #20 (42.14 lb/yd^3 or 25 kg/m^3)	Expansive Additive
6	Mn/DOT 3U18 w/ Denka 100R (50.56 lb/yd^3 or 30 kg/m^3)	Expansive Additive
7	Mn/DOT 3U18 w/ Denka 100R (42.14 lb/yd^3 or 25 kg/m^3)	Expansive Additive
8	Mn/DOT 3U18 w/ Peramin SRA330	Shrinkage Reducing Admixture
9	Mn/DOT 3U18 w/ Eclipse Plus	Shrinkage Reducing Admixture
10	Mn/DOT 3U18 w/ Tetraguard AS20	Shrinkage Reducing Admixture
11	Mn/DOT 3U18 w/ Solite (LWFA)	Internal Curing
12	Mn/DOT 3U18 w/ Hydrocure (LWFA)	Internal Curing

CURING COMPOUND DESCRIPTIONS	TYPE OF CONCRETE CURING COMPOUND
Sealtight 1600 - White **(CONTROL)**	Water-Base, Wax-Base
Sealtight 2255 - White	Poly-Alphamethylstyrene

5.0 LABORATORY TESTING

The laboratory testing process was broken down into three phases for this study. Phase I testing was comprised of tests with short durations and was used to eliminate poor performing materials from the more in-depth testing of Phase II. Slump, unit weight, and air content were measured in both phases for informational purposes. Phase I testing included time of set, change in height, and compressive strength. The mix designs that performed acceptably in Phase I were mixed again and tested for compressive strength, length change, freeze/thaw durability, permeability, and concrete-to-concrete bond strength in Phase II. The curing compounds were evaluated in Phase III, using the water retention test.

5.1 Phase I Testing

As previously stated, this testing phase was comprised of tests with short durations and was used to eliminate poor performing materials from the more in-depth testing of Phase II. The mix designs and test results for each patch material can be found in Appendix A.

During the concrete mixing process, two of the patch material mixes that included shrinkage reducing admixtures (SRA's) could not be mixed satisfactorily and they were eliminated from the testing phase. Neither the patch material containing Peramin SRA330 (Sample 8) nor the patch material containing Eclipse Plus (Sample 9) could entrain a sufficient amount of air when tested with a Type B air meter, in accordance with ASTM C 231, even when extremely high amounts of compatible air entraining admixtures were added.[6] WisDOT experience shows that some SRA's have a negative impact on the air entraining capabilities of a concrete mix. It should be noted that not all of the SRA's performed poorly; the Tetraguard AS20 SRA entrained a sufficient amount of air without difficulty and was included in the testing.

- 5.1.1 Slump -

Following the procedure designated in ASTM C 143, the slump of the concrete was measured after it was mixed. Although a maximum slump of 1 inch is specified for the Mn/DOT 3U18 concrete mix design, all slumps were considered acceptable in this study. Instead of regulating the slump, all modified concretes were strictly held to the same w/c used in the control. The slump test gives some information on the consistency and workability of the concrete. The results can be found in Table 3 on the following page.

- 5.1.2 Unit Weight -

The unit weight of the concrete was determined in accordance with ASTM C 138, using the air meter measuring bowl. There was no desired range of values for unit weight for this study. Instead, this testing was conducted to learn more about the physical properties of the various concrete samples. The unit weight results are also shown in Table 3.

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[6] Hardened air contents of these samples were also measured to check the accuracy of the air meter. The results were very similar and it was concluded that there was an inadequate amount of entrained air in the samples.

- 5.1.3 Air Content -

The concrete samples were tested for fresh air content following ASTM C 231, using a properly calibrated Type B air meter. Air content is important because it affects the compressive strength and the freeze/thaw durability of the concrete. An air content between 4 and 7 percent is specified for Mn/DOT 3U18. A 6 percent air content was targeted for this study, but it was very difficult to achieve when mixing such a small volume of concrete, even with very high doses of air entraining admixtures. Due to these difficulties, the lower limit of four percent air content was considered acceptable for concrete samples mixed in Phase I. Table 3, below, shows the air contents achieved in each patch material sample.

Table 3. Phase I Slump, Unit Weight, and Air Content Test Results

SAMPLE NUMBER	MODIFIED PATCH MATERIAL DESCRIPTIONS	SLUMP (in.)	UNIT WEIGHT (lb/ft^3)	AIR CONTENT (%)
1	Mn/DOT 3U18 **(CONTROL)**	2.25	143.59	4.5
2	Mn/DOT 3U18 w/ Type K Cement	8.75	141.07	5.0
3	Mn/DOT 3U18 w/ Komponent	3.00	142.51	4.8
4	Mn/DOT 3U18 w/ Denka #20 (50.56 lb/yd^3 or 30 kg/m^3)	2.50	142.35	5.0
5	Mn/DOT 3U18 w/ Denka #20 (42.14 lb/yd^3 or 25 kg/m^3)	3.25	141.79	5.0
6	Mn/DOT 3U18 w/ Denka 100R (50.56 lb/yd^3 or 30 kg/m^3)	2.00	143.33	4.4
7	Mn/DOT 3U18 w/ Denka 100R (42.14 lb/yd^3 or 25 kg/m^3)	1.50	142.97	4.3
10	Mn/DOT 3U18 w/ Tetraguard AS20	1.00	144.11	4.0
11	Mn/DOT 3U18 w/ Solite (LWFA)	0.00	141.31	4.0
12	Mn/DOT 3U18 w/ Hydrocure (LWFA)	0.25	141.63	4.0

- 5.1.4 Time of Set -

Time of set of the concrete was determined following ASTM C 403. Time of setting, as defined in the 2003 Annual Book of ASTM Standards, is "the elapsed time from the addition of mixing water to a cementitious mixture until the mixture reaches a specified degree of rigidity as measured by a specific procedure." Simply put, the time of set is the length of time the concrete is workable and a time of no less than 15 minutes is generally desirable. As shown in Figure 4 on the following page, the patch material mortar[7] was

[7] Following ASTM C 403 procedure, the patch material was wet-sieved through a No. 4 (4.75-mm) sieve, thus removing the coarse aggregate (3/8-inch pea gravel) from the patch material. This was done to eliminate the possibility of the needle coming into contact with any coarse aggregate and reporting inaccurate resistance readings.

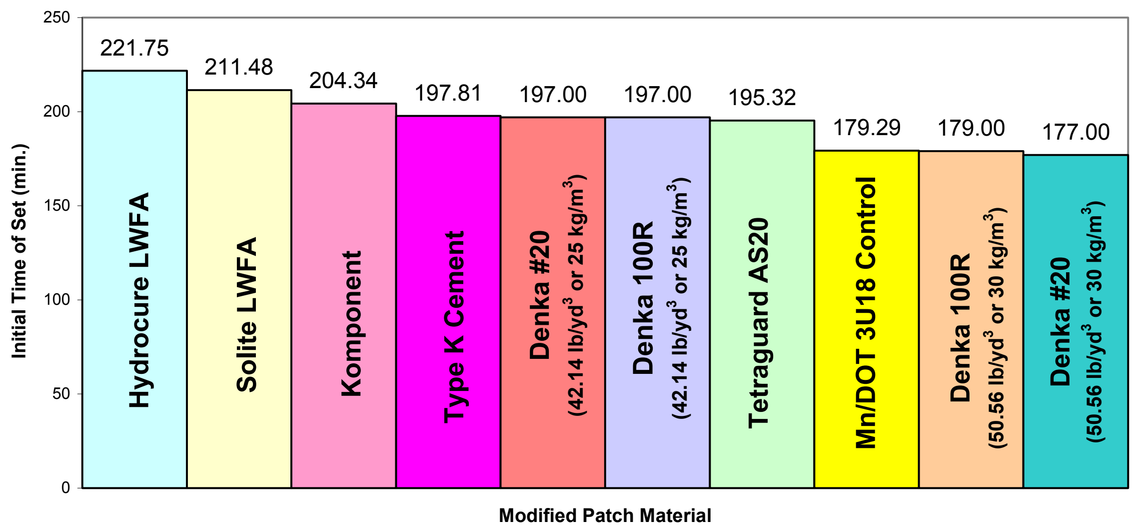
placed into a 6-inch high, 6-inch diameter cylindrical mold. At regular intervals, the resistance of the mortar to penetration by a standard needle was measured. As the resistance approached 500 psi, the measurement intervals were shortened. Once the mortar was able to resist a pressure of 500 psi, the initial time of set had been reached and the testing was complete. Proprietary rapid setting concrete patch materials typically reach the initial time of set in 15 to 25 minutes.

Figure 4. Time of Set Testing

A needle, attached to the hydraulic loading device, penetrates the mortar at regular intervals until it meets a resistance of 500 psi. The time at which the mortar resists 500 psi is its initial time of set.

The time of set test results, presented in Figure 5 on the following page, show that all of the samples took much longer to achieve an initial set than proprietary concrete patch materials. The Mn/DOT 3U18 control took nearly 3 hours to achieve an initial set. Both Denka products at the higher dosage rate of 50.56 lb/yd^3 (30 kg/m^3) slightly lowered the initial time of set of the Mn/DOT 3U18 patch material, but all of the other products increased the initial time of set, with the lightweight fine aggregate products adding over 30 minutes to the set time. Thus, all of the samples surpassed the 15-minute minimum; and since there is no maximum time of set constraint, none of the samples were eliminated from Phase II based on the time of set test results.

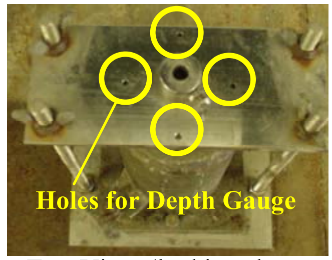
Figure 5. Time of Set Test Results



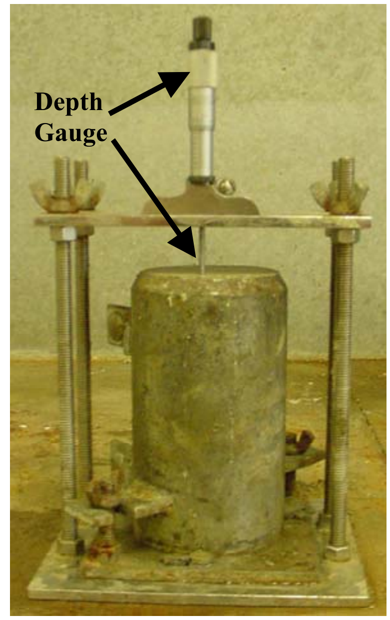
- 5.1.5 Change in Height -

The change in height testing was conducted in accordance with ASTM C 1090, using only the mortar portion of the concrete samples (i.e. the coarse aggregate was sieved out). This test determines the volume change a mortar undergoes when it sets and hardens under confinement. As shown in Figure 6 on the following page, the cylindrical mold confined the mortar on the bottom and around the circumference, leaving only the top exposed. To perform the test, the mold was placed into the micrometer bridge apparatus and secured. The top of the micrometer bridge had four holes where the depth gauge was inserted to measure the distance to the concrete surface, or to the glass plate for the initial readings. The thickness of the glass plate was added onto the initial readings and the initial average depth measurement was calculated (V_i). The average depth readings were calculated for the 1-day, 3-day, and 7-day ages (V_{1day}, V_{3day}, V_{7day}).

Figure 6. Change in Height Testing



Top View (looking down at the micrometer bridge)



The cylinder mold was filled with mortar, covered with a glass plate, placed into the micrometer bridge apparatus, and bolted down. The plunger was lowered until it made contact with the glass plate and a 3 lb weight was placed on top of the plunger (left). The position of the plunger was secured, the weight was removed, and the initial height measurements were recorded by inserting the depth gauge through the holes in the top of the micrometer bridge (center). The depth gauge measures the distance to the surface of the concrete (right), or to the surface of the glass plate for the initial readings. After the initial measurements were taken, the apparatus was covered and placed in moist storage. Before the 1-day reading, the plunger and glass plate were removed from the apparatus.

The height change percentage for each age was calculated by the following equation:

$$H_t = \frac{V_i - V_t}{V} * 100$$

Where H_t = Height Change at Age t, %
V_i = Initial Depth Measurement
$V_t = V_{1day}$, V_{3day}, or V_{7day}
V = Height of Cylinder Mold, 6 inches

Thus, a negative value for H_t represents shrinkage and a positive value represents expansion.

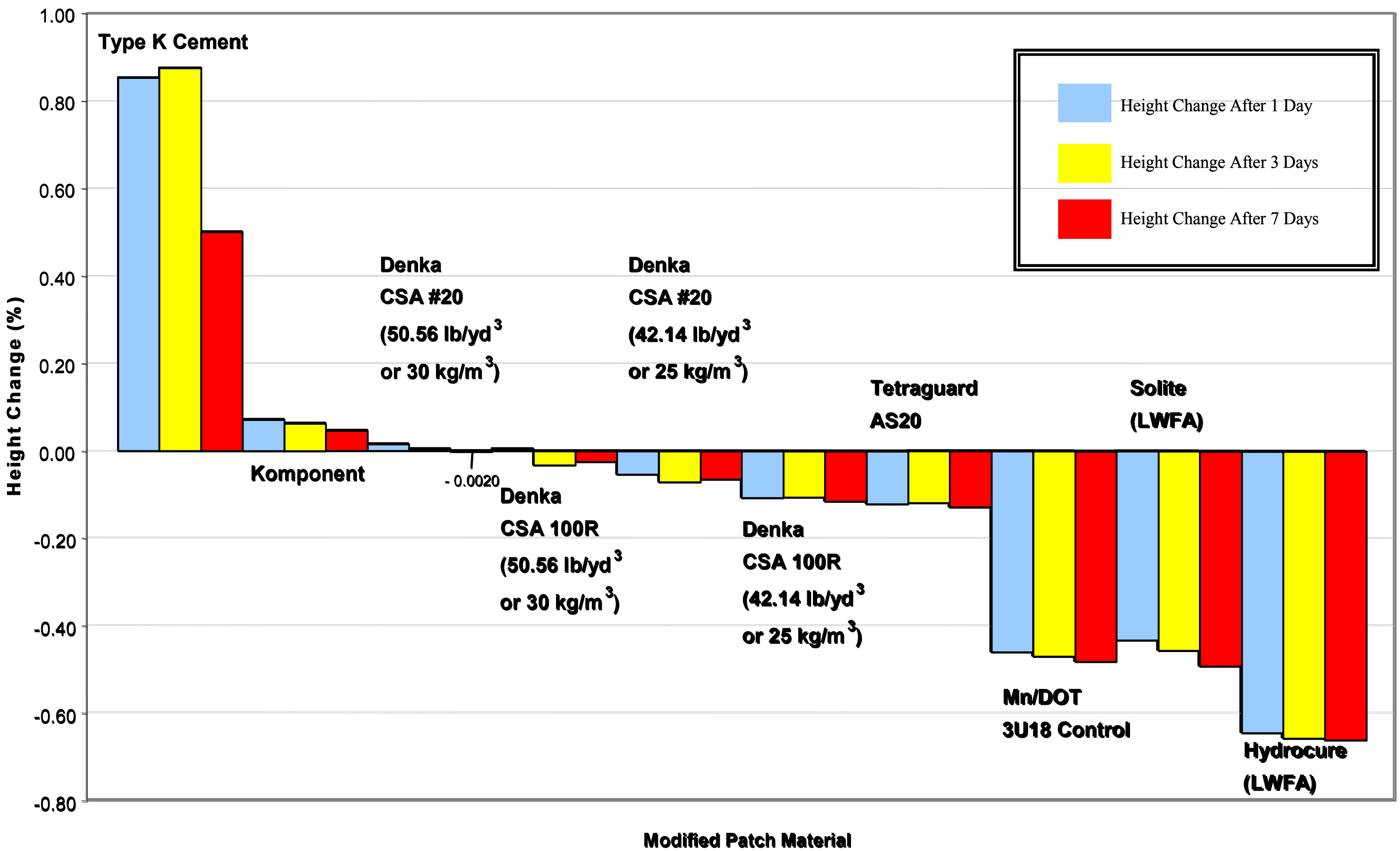
The change in height test results are shown in Table 4 below and Figure 7 on the following page. The shrinkage, or change in height in the negative direction, shown by the control was set as the maximum allowable shrinkage for all of the test samples. Only the patch material samples containing the lightweight fine aggregate (Sample 11 and Sample 12) showed more shrinkage than the control after 7 days. The samples modified with Type K cement and Komponent (Sample 2 and Sample 3) showed expansion after seven days.

Table 4. Change in Height Test Results

SAMPLE NUMBER	MODIFIED PATCH MATERIAL DESCRIPTIONS	HEIGHT CHANGE (%)		
		1 DAY	3 DAYS	7 DAYS
1	Mn/DOT 3U18 **(CONTROL)**	-0.460	-0.469	-0.481
2	Mn/DOT 3U18 w/ Type K Cement	0.852	0.875	0.500
3	Mn/DOT 3U18 w/ Komponent	0.071	0.063	0.046
4	Mn/DOT 3U18 w/ Denka #20 (50.56 lb/yd^3 or 30 kg/m^3)	0.015	0.004	-0.002
5	Mn/DOT 3U18 w/ Denka #20 (42.14 lb/yd^3 or 25 kg/m^3)	-0.054	-0.071	-0.065
6	Mn/DOT 3U18 w/ Denka 100R (50.56 lb/yd^3 or 30 kg/m^3)	0.004	-0.033	-0.025
7	Mn/DOT 3U18 w/ Denka 100R (42.14 lb/yd^3 or 25 kg/m^3)	-0.108	-0.106	-0.115
10	Mn/DOT 3U18 w/ Tetraguard AS20	-0.121	-0.119	-0.129
11	Mn/DOT 3U18 w/ Solite (LWFA)	-0.433	-0.456	-0.492
12	Mn/DOT 3U18 w/ Hydrocure (LWFA)	-0.644	-0.656	-0.660

Negative height change values indicate a change in height in the negative direction, or shrinkage.

Figure 7. Change in Height Test Results



- 5.1.6 Compressive Strength -

A set of two 8-inch high, 4-inch diameter cylinders were tested for compressive strength at 4 hours, 6 hours, 8 hours, 1 day, 3 days, 7 days, and 28 days in accordance with ASTM C 39. As shown in Figure 8 below, a compressive axial load was applied to the concrete cylinder at a constant rate until failure occurred. The compressive strength of the cylinder was determined by measuring the maximum load it was able to resist before failure and dividing that by the cross-sectional area of the cylinder.

Figure 8. Compressive Strength Testing

The compressive strength testing machine is controlled by a computer that monitors the rate at which the load is applied to the concrete cylinder and the load at which the concrete cylinder reaches failure (left). A new cylinder is placed into the testing machine (center). The cylinder reaches failure after it could no longer withstand the increasing compressive load (right).

The compressive strengths of each set of cylinders were averaged and the results are shown in Table 5 on the following page. The compressive strengths have also been graphed to show the rate at which strength is gained in each patch material; the early results (at 4, 6, 8, and 24 hours) are shown in Figure 9 on page 20, and all of the results are shown in Figure 10 on page 21. As with any concrete, compressive strength increases with maturity during the ongoing process of hydration. Variations in the strength of concrete of the same age can occur and are normal, due to inadvertent variations in the casting of the cylinders (i.e. varying levels of consolidation). Thus, some of the patch materials showed a drop in compressive strength between 3 and 7 days or between 7 and 28 days.

Table 5. Compressive Strength Test Results

SAMPLE NUMBER	MODIFIED PATCH MATERIAL DESCRIPTIONS	COMPRESSIVE STRENGTH (psi)						
		4 HR.	6 HR.	8 HR.	1 DAY	3 DAYS	7 DAYS	28 DAYS
1	Mn/DOT 3U18 **(CONTROL)**	70	240	670	4425	6755	7210	6885
2	Mn/DOT 3U18 w/ Type K Cement	NA	NA	255	1395	2410	3385	5375
3	Mn/DOT 3U18 w/ Komponent	45	155	545	2945	4200	5170	5175
4	Mn/DOT 3U18 w/ Denka #20 (50.56 lb/yd^3 or 30 kg/m^3)	50	305	895	4215	5020	5555	6530
5	Mn/DOT 3U18 w/ Denka #20 (42.14 lb/yd^3 or 25 kg/m^3)	55	235	730	3945	5490	5670	6180
6	Mn/DOT 3U18 w/ Denka 100R (50.56 lb/yd^3 or 30 kg/m^3)	70	310	1070	4225	6050	6000	6850
7	Mn/DOT 3U18 w/ Denka 100R (42.14 lb/yd^3 or 25 kg/m^3)	55	195	885	4150	6335	6145	6635
10	Mn/DOT 3U18 w/ Tetraguard AS20	45	160	695	3545	4850	5490	6590
11	Mn/DOT 3U18 w/ Solite (LWFA)	45	155	680	3715	6045	6965	6165
12	Mn/DOT 3U18 w/ Hydrocure (LWFA)	35	185	235	4425	6535	7235	6590

All of the cylinders, except for those containing Type K cement, had hardened enough to be tested at ages of 4 and 6 hours. The cylinders made with the patch material containing Type K cement did not harden enough to be tested until they had reached an age of 8 hours.

For current dowel bar retrofit projects, WisDOT's DBR warranty requires rapid set patch materials to reach a compressive strength of 3,000 psi at an age of three hours. The high early strength of the patch material is necessary so that traffic can be placed back on the retrofitted lanes soon after the process is completed. As shown in Table 5 and Figure 9, most of the patch materials, including the control, did not achieve a compressive strength of 3,000 psi until sometime between 8 hours and 1 day. The patch material made with Type K cement (Sample 2) was the slowest to gain its strength, not achieving a strength of 3,000 psi until sometime between 3 and 7 days.

Since DBR projects often involve traffic lane closures exceeding 24 hours, the compressive strength requirement (i.e. 3,000 psi in 3 hours) of WisDOT's current warranty specification may not always be relevant. Thus, the compressive strength test results were not used as a testing constraint for this study, and none of the patch materials were eliminated from Phase II testing based on the compressive strength test results.

Based on the laboratory testing results of this study, the modified Mn/DOT 3U18 patch materials that show the most promise will be tested in field applications. Pending the results of this field evaluation, if it is demonstrated that a slower rate of strength gain does not result in extended traffic delays and does not have any negative impacts on the patch material (i.e. the patch material is able to withstand the thermal stresses exerted by the surrounding pavement and the steel dowel bars), modifications to the DBR warranty compressive strength requirement, for DBR projects with lane closures of at least 24 hours, will be recommended.

Figure 9. Compressive Strength Test Results Showing Rate of Early Strength Gain

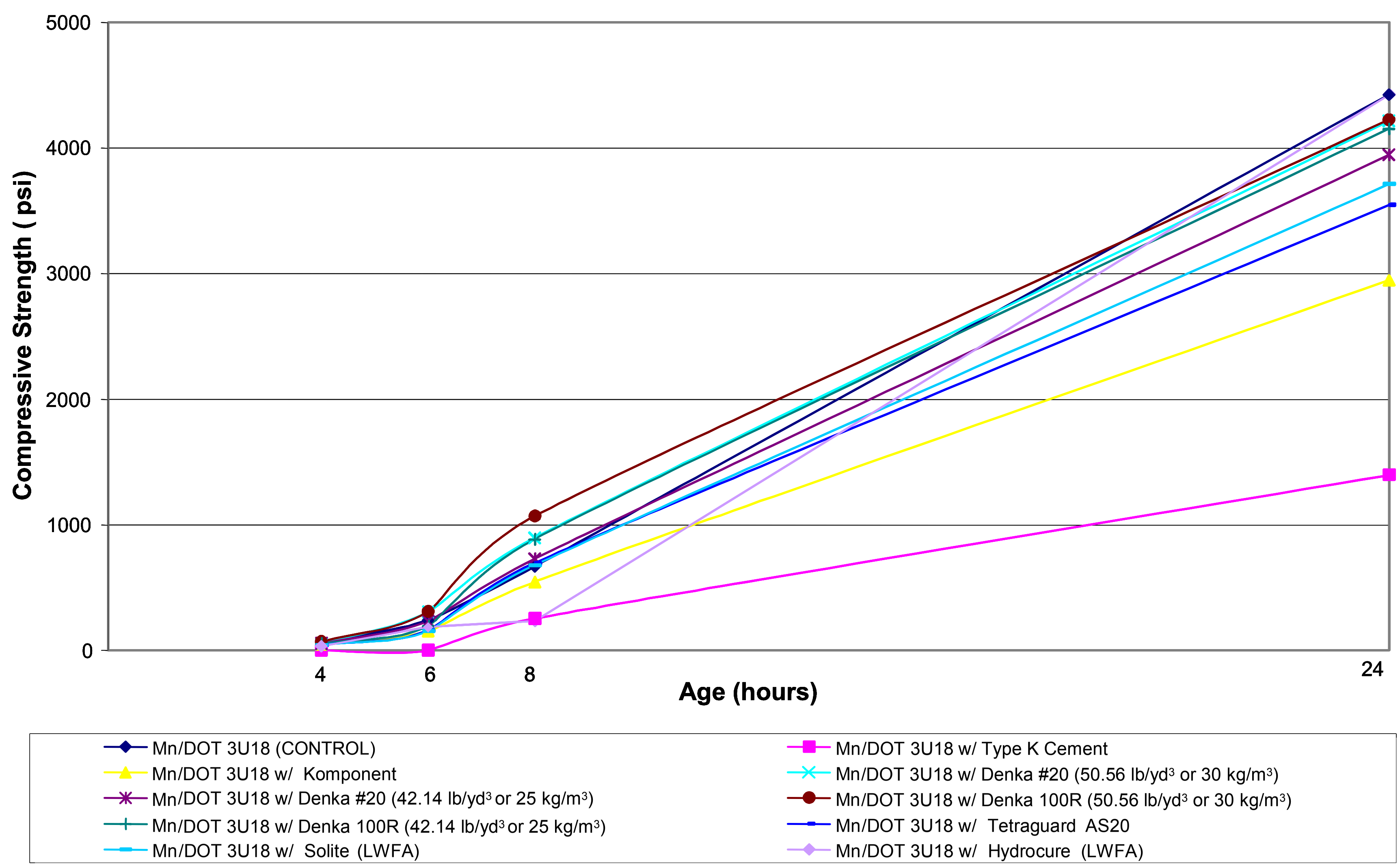
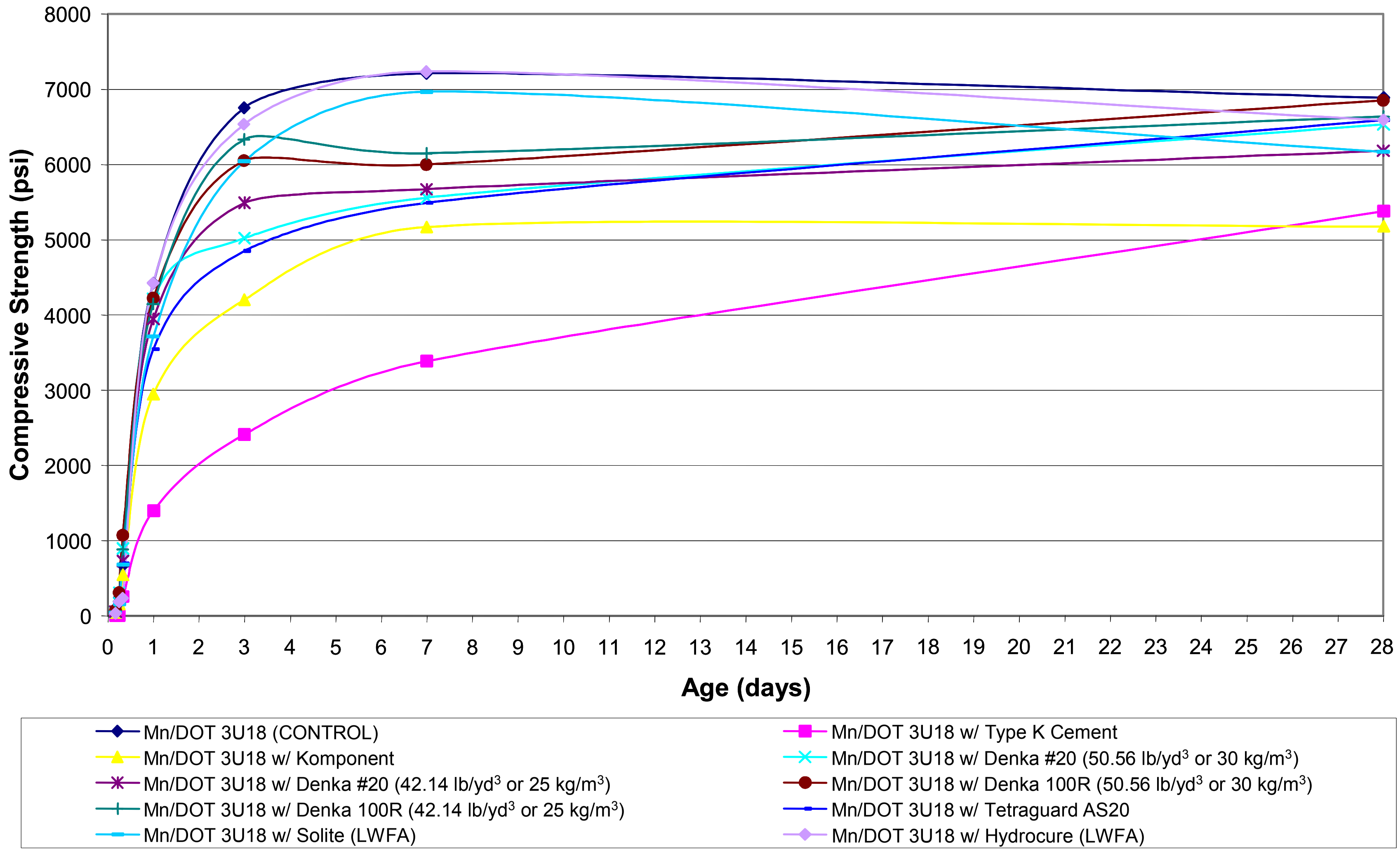


Figure 10. Compressive Strength Test Results Showing Rate of Strength Gain



- 5.1.7 Phase I Test Results Summary -

The status of each patch material after Phase I testing is shown in Table 6 on the following page. Sample 2, containing the only expansive cement tested (Type K cement), was approved for Phase II testing even though its slow rate of compressive strength gain might make it impractical for use in some DBR projects. Sample 3, containing the Komponent expansive additive, also advanced to Phase II testing. Based on the change in height test results for the patch materials containing the Denka expansive additives (Samples 4 through 7), it was determined that the higher dosage rate (50.56 lb/yd^3 or 30 kg/m^3) was more effective at reducing shrinkage than the lower dosage rate (42.14 lb/yd^3 or 25 kg/m^3) and the CSA #20 product performed better than the CSA 100R product. From these findings and the desire to select just one Denka product, only Sample 4 (containing Denka CSA #20, 50.56 lb/yd^3 or 30 kg/m^3) advanced to Phase II of the testing process; Samples 5,6, and 7 were eliminated. Based on air entraining problems during the mixing process, two of the samples containing shrinkage reducing admixtures, Sample 8 (containing Peramin SRA330) and Sample 9 (containing Eclipse Plus), were eliminated from the study without being tested. Sample 10, containing the other SRA (Tetraguard AS20), was approved for Phase II testing. Sample 11 (containing Solite) and Sample 12 (containing Hydrocure), the two lightweight fine aggregate mixes designed to provide internal curing, were eliminated from Phase II testing due to poor test results from the change in height test.[8]

In summary, the following samples advanced to Phase II of the testing process:

- Sample 1: Mn/DOT 3U18 (Control),
- Sample 2: Mn/DOT 3U18 w/ Type K cement,
- Sample 3: Mn/DOT 3U18 w/ Komponent,
- Sample 4: Mn/DOT 3U18 w/ Denka CSA #20 (50.56 lb/yd^3 or 30 kg/m^3), and
- Sample 10: Mn/DOT 3U18 w/ Tetraguard AS20.

[8] Although the samples containing lightweight fine aggregate (Sample 11 and Sample 12) did not progress to Phase II testing, upon the completion of this research study, additional testing was conducted on a patch material containing a higher percentage of Hydrocure LWFA. The results of the testing are included in Appendix C and show that internal curing can successfully reduce shrinkage.

Table 6. Patch Material Status After Phase I Testing

SAMPLE NUMBER	MODIFIED PATCH MATERIAL DESCRIPTIONS	SHRINKAGE REDUCTION METHOD	TESTING STATUS
1	**Mn/DOT 3U18 (CONTROL)**	**None**	**PHASE II**
2	**Mn/DOT 3U18 w/ Type K Cement**	**Expansive Cement**	**PHASE II**
3	**Mn/DOT 3U18 w/ Komponent**	**Expansive Additive**	**PHASE II**
4	**Mn/DOT 3U18 w/ Denka #20 (50.56 lb/yd^3 or 30 kg/m^3)**	**Expansive Additive**	**PHASE II**
5	Mn/DOT 3U18 w/ Denka #20 (42.14 lb/yd^3 or 25 kg/m^3)	Expansive Additive	ELIMINATED
6	Mn/DOT 3U18 w/ Denka 100R (50.56 lb/yd^3 or 30 kg/m^3)	Expansive Additive	ELIMINATED
7	Mn/DOT 3U18 w/ Denka 100R (42.14 lb/yd^3 or 25 kg/m^3)	Expansive Additive	ELIMINATED
8	Mn/DOT 3U18 w/ Peramin SRA330	Shrinkage Reducing Admixture	ELIMINATED
9	Mn/DOT 3U18 w/ Eclipse Plus	Shrinkage Reducing Admixture	ELIMINATED
10	**Mn/DOT 3U18 w/ Tetraguard AS20**	**Shrinkage Reducing Admixture**	**PHASE II**
11	Mn/DOT 3U18 w/ Solite (LWFA)	Internal Curing	ELIMINATED
12	Mn/DOT 3U18 w/ Hydrocure (LWFA)	Internal Curing	ELIMINATED

5.2 Phase II Testing

This testing phase was comprised of more comprehensive tests and the results were used to determine the best performing patch materials overall. The patch material mix designs and corresponding test results can be found in Appendix B.

- 5.2.1 Slump, Unit Weight, and Air Content -

The concrete samples mixed for Phase II testing contained higher dosages of air entraining admixtures which slightly affected their physical properties, as shown in Table 7 below. The amount of air entraining admixture was increased in an attempt to achieve a 6 percent air content in the patch materials. Although all of the samples fell below the targeted 6 percent air content, they all exceeded the minimum acceptable air content of 4 percent.

Table 7. Phase II Slump, Unit Weight, and Air Content Test Results

SAMPLE NUMBER	MODIFIED PATCH MATERIAL DESCRIPTIONS	SLUMP (in.)	UNIT WEIGHT (lb/ft^3)	AIR CONTENT (%)
1	Mn/DOT 3U18 **(CONTROL)**	1.75	143.53	4.6
2	Mn/DOT 3U18 w/ Type K Cement	7.75	141.33	5.2
3	Mn/DOT 3U18 w/ Komponent	1.75	142.03	4.8
4	Mn/DOT 3U18 w/ Denka #20 (50.56 lb/yd^3 or 30 kg/m^3)	2.25	142.71	5.0
10	Mn/DOT 3U18 w/ Tetraguard AS20	0.25	142.81	5.0

- 5.2.2 Compressive Strength -

Since the air contents of the concrete samples were increased in Phase II, additional compressive strength testing was conducted to find out more about the physical properties of these concrete samples. In Phase II, compressive strength was recorded at 1, 3, and 7 days and the average results of two cylinders for each age are shown in Table 8 below. The results are consistent with those from Phase I, showing that all the patch materials, with the exception of Sample 2 (containing Type K cement), reached 3,000 psi within 1 day. The patch material modified with Type K cement (Sample 2) again was unable to reach a compressive strength of 3000 psi until between 3 and 7 days.

Table 8. Compressive Strength Test Results

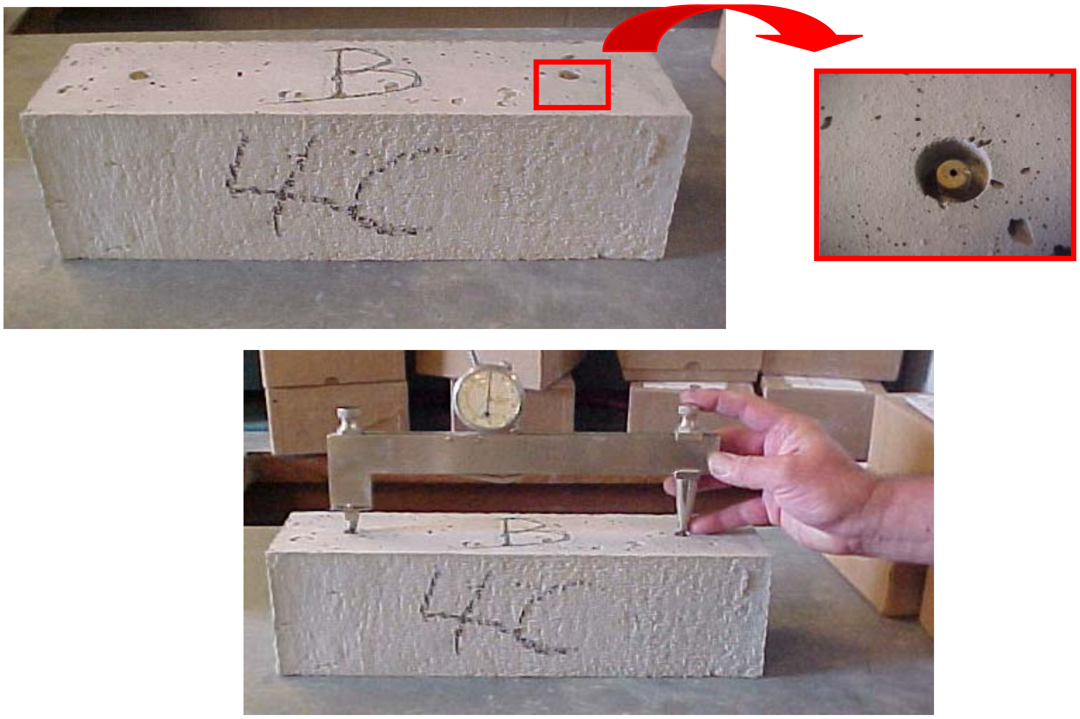
SAMPLE NUMBER	MODIFIED PATCH MATERIAL DESCRIPTIONS	COMPRESSIVE STRENGTH (psi)		
		1 DAY	3 DAYS	7 DAYS
1	Mn/DOT 3U18 **(CONTROL)**	4545	5325	6180
2	Mn/DOT 3U18 w/ Type K Cement	1680	2700	3480
3	Mn/DOT 3U18 w/ Komponent	3175	4410	4654
4	Mn/DOT 3U18 w/ Denka #20 (50.56 lb/yd^3 or 30 kg/m^3)	3955	5965	6790
10	Mn/DOT 3U18 w/ Tetraguard AS20	3970	5095	5120

- 5.2.3 Length Change -

Change in length testing, following ASTM C 341, was performed to evaluate the volume change of the hardened concrete.[9] Two gauge studs were cast within each rectangular concrete prism and the prisms were covered with an impervious plastic membrane for the first 23 hours. After 23 hours, the concrete prisms were removed from the molds and immersed in lime-saturated water for an additional hour. At an age of 24 hours, the initial length change reading was taken by measuring the distance between the two studs (see Figure 11 on the following page). Then, the block was flipped over and the measurement was taken on the opposite side. The two measurements were averaged to find the initial length for each prism. This procedure was repeated at the ages of 3, 7, 28, 56, and 90 days. After the first 24 hours, the concrete prisms were stored in the laboratory under conditions that qualify as "air storage" according to ASTM C 341.

[9] This test procedure was slightly modified by using rectangular concrete prisms made in the laboratory instead of drilled or sawed specimens.

Figure 11. Length Change Testing



Two gauge studs are embedded into each end of the concrete (top). The feet of the comparator are moved until they slide into the top of each stud and the measurement of the specimen is recorded (bottom).

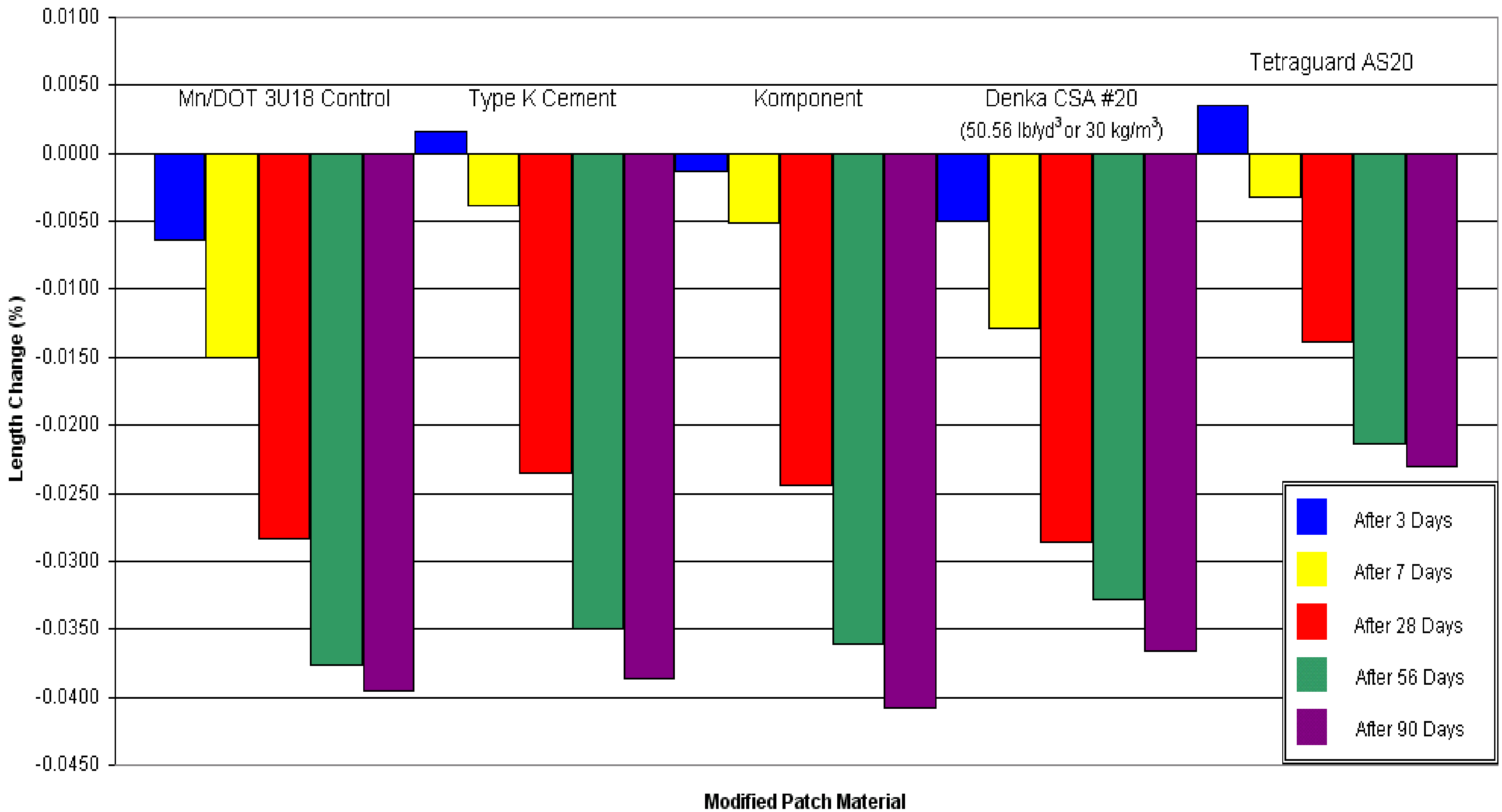
The length change test results, which are the averages of three rectangular prisms for each sample, are shown in Table 9 below and Figure 12 on the following page. At 90 days, the patch material modified with Komponent (Sample 3), which showed slight expansion in the change in height test of Phase I after 7 days (which tested mortar only), showed more shrinkage than the control after 90 days. The other modified patch materials (containing Type K cement, Denka CSA #20, and Tetraguard AS20) showed a reduction in shrinkage compared to the control, with the Tetraguard AS20 modified patch material showing the least amount of shrinkage after 90 days (approximately 42 percent less than the control mix).

Table 9. Length Change Test Results

SAMPLE NUMBER	MODIFIED PATCH MATERIAL DESCRIPTIONS	LENGTH CHANGE (%)				
		3 DAYS	7 DAYS	28 DAYS	56 DAYS	90 DAYS
1	Mn/DOT 3U18 **(CONTROL)**	-0.0064	-0.0150	-0.0284	-0.0377	-0.0396
2	Mn/DOT 3U18 w/ Type K Cement	0.0016	-0.0038	-0.0236	-0.0350	-0.0387
3	Mn/DOT 3U18 w/ Komponent	-0.0013	-0.0052	-0.0244	-0.0362	-0.0408
4	Mn/DOT 3U18 w/ Denka #20 (50.56 lb/yd^3 or 30 kg/m^3)	-0.0050	-0.0129	-0.0286	-0.0328	-0.0367
10	Mn/DOT 3U18 w/ Tetraguard AS20	0.0035	-0.0033	-0.0138	-0.0213	-0.0230

Negative length change values indicate a change in length in the negative direction, or shrinkage.

Figure 12. Length Change Test Results



- 5.2.4 Freeze/Thaw Durability -

The concrete samples were also tested for freeze/thaw durability in accordance with ASTM C 666 Procedure A, using 5 percent sodium chloride solution. The procedure for this test was slightly modified to accommodate the staggered dates at which the various concrete samples were mixed. The rectangular concrete beams were removed from their molds within the first 24 hours and placed in a moist storage room, where they were allowed to cure for 28 days. After the 28-day cure, in order to test all of the concrete samples in the same freeze/thaw chamber, the beams that were mixed at earlier dates were placed in a freezer to suspend the curing process until the other samples that had been mixed at later dates were ready. Before the beams were placed in the freezer, they were allowed to air dry for 48 hours to prevent any damage.

As shown in Figure 13 below, once all of the beams had cured for 28 days, they were placed in metal containers with open tops, and filled with the sodium chloride solution. The containers were then loaded into the freeze/thaw chamber and underwent 300 cycles of freezing and thawing. The chamber was stopped after every 100 cycles to weigh the specimens and determine their loss in mass.

Figure 13. Freeze/Thaw Testing

The concrete specimens are placed in metal containers and loaded into the freeze/thaw chamber. The specimens are covered with a 5 percent sodium chloride solution and run through 300 freeze/thaw cycles. After every 100 cycles, the specimens are removed from the chamber and their loss in mass is documented.

The freeze/thaw test results, which are the averages of three beams for each sample, are shown in Table 10 below. WisDOT defines failure of the freeze/thaw test as any concrete specimen that exceeds a 10 percent loss in mass after 300 cycles. A standard WisDOT concrete mix typically loses about 2 percent of mass after 300 cycles. The patch materials containing Denka CSA #20 (Sample 4) and Tetraguard AS20 (Sample 10) showed greater losses in mass than the control, but still met WisDOT specifications with mass losses less than 10 percent. The three specimens that met WisDOT specifications after 300 cycles are shown in Figure 14 at the bottom of the page. The patch materials containing Type K cement and Komponent (Samples 2 and 3) both had losses in mass greater than 10 percent, thus both patch materials failed the freeze-thaw testing (see Figure 15 on the following page).

Table 10. Freeze/Thaw Test Results

SAMPLE NUMBER	MODIFIED PATCH MATERIAL DESCRIPTIONS	LOSS IN MASS (%) 100 CYCLES	200 CYCLES	300 CYCLES	WisDOT SPEC. 10% MAX. @ 300 CYCLES
1	Mn/DOT 3U18 **(CONTROL)**	0.0	0.6	1.7	PASS
2	Mn/DOT 3U18 w/ Type K Cement	6.5	10.2	15.8	FAIL
3	Mn/DOT 3U18 w/ Komponent	0.7	9.5	25.5	FAIL
4	Mn/DOT 3U18 w/ Denka #20 (50.56 lb/yd^3 or 30 kg/m^3)	-0.1	0.7	5.4	PASS
10	Mn/DOT 3U18 w/ Tetraguard AS20	1.4	4.2	9.9	PASS

A negative loss in mass (a gain in mass) is due to hydration and chloride ion gains.

Figure 14. Freeze/Thaw Beams Meeting WisDOT Specifications

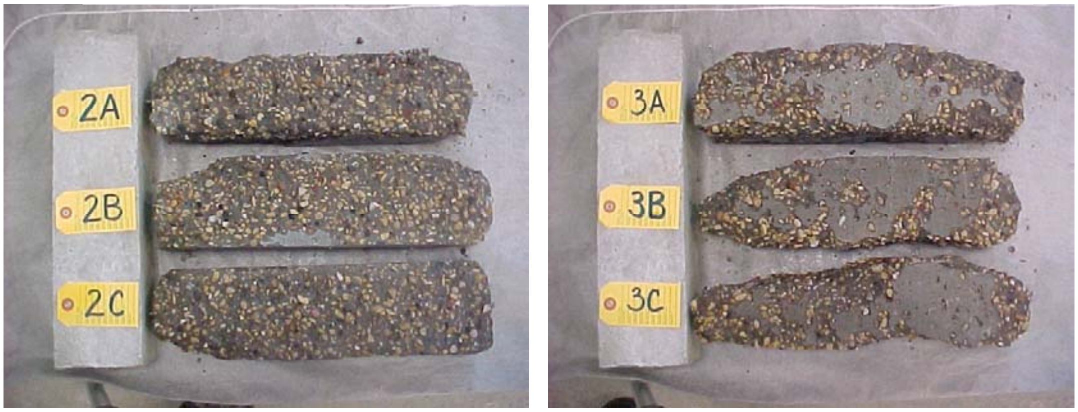
Mn/DOT 3U18 (Control)

Denka CSA #20
(50.56 lb/yd^3 or 30 kg/m^3)

Tetraguard AS20

The Mn/DOT 3U18, Denka CSA #20 (50.56 lb/yd^3 or 30 kg/m^3), and Tetraguard AS20 concrete specimens are shown above after being subjected to 300 freeze/thaw cycles. These are the only specimens that lost less than 10 percent of their mass, meeting WisDOT's specifications.

Figure 15. Freeze/ Thaw Beams Not Meeting WisDOT Specifications



Type K Cement **Komponent**

Three concrete specimens, for both the Type K cement and the Komponent, are shown above after being subjected to 300 freeze/thaw cycles. All of the specimens lost more than 10 percent of their mass, failing WisDOT's specifications

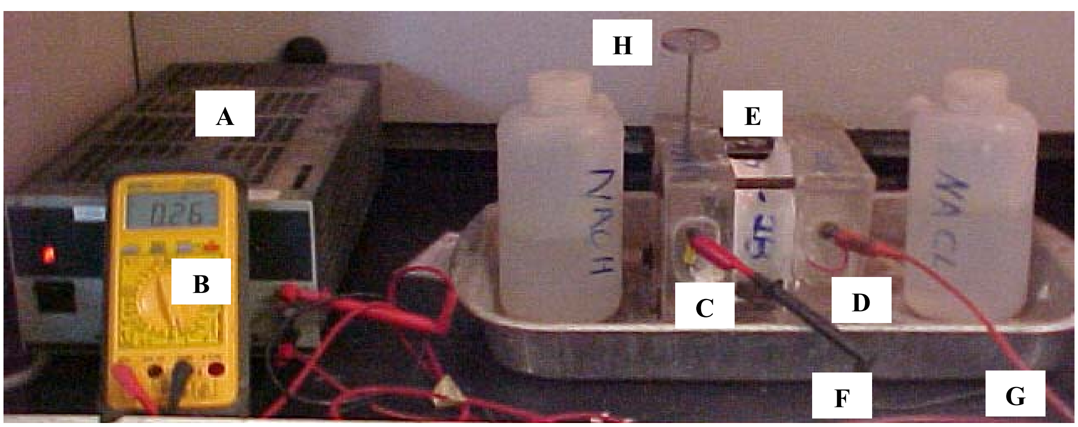
- 5.2.5 Permeability -

Permeability tests were conducted on the concrete samples in accordance with ASTM C 1202. Permeability testing measures the electrical conductivity of the patch material samples. ASTM C 1202 states that, "the total charge passed through the patch material is related to the resistance of the specimen to chloride ion penetration".

This procedure was also slightly modified to accommodate the staggered dates at which the various concrete samples were mixed. The 4-inch diameter concrete cylinders were stripped from their molds within the first 24 hours and placed in a moist storage room. After curing for 7 days, the concrete cylinders were removed from the storage room and cut into 2-inch slices. One of the slices from each sample was air dried for 24 hours to prevent damage and was placed in the freezer to suspend the curing process. The other slices were returned to the moist storage room until they reached ages of 28 and 90 days. After these slices reached their appropriate ages, they were also air dried and placed in the freezer.

When the samples were ready to test, they were allowed to thaw at air temperature. Then, the circumference of each slice was coated with a rapid setting, two-part, watertight epoxy. Once the epoxy had set up, the open faces of the slice were beadblasted to remove any dirt or epoxy. Then, the specimen was placed in a vacuum desiccator. After 3 hours, the specimen was covered with de-aerated water within the vacuum desiccator and the vacuum pump continued to run for another hour. The specimen was stored in the sealed vacuum desiccator, submerged in de-aerated water, overnight. The following morning, the specimen was removed from the vacuum and placed into the permeability cell (see Figure 16 below). The edges where the specimen touched the cell were sealed with caulk. After the caulk had set up, one side of the cell was filled with a 3.0 percent NaCl solution and the other side was filled with 0.3 N NaOH solution. A power supply was connected to the cell, negative lead wire on the NaCl side and positive lead wire on the NaOH side, and the power was turned on. The amperes passing through the cell were recorded initially, and every 30 minutes after that, for a total of 360 minutes. If the temperature reached 190° F before 360 minutes had elapsed, the test was terminated to avoid damaging the equipment or boiling the solutions.

Figure 16. Permeability Testing



An electrical current from the power supply (A) is monitored on the voltmeter (B) as it is passed through the specimen. One end of the specimen is immersed in a sodium hydroxide (NaOH) solution (C) and the other end of the specimen is immersed in a sodium chloride (NaCl) solution (D). The specimen itself (E) is coated with epoxy to prevent any solution from escaping through the sides. The positive lead wire (F) is attached to the NaOH cell and the negative lead wire (G) is attached to the NaCl cell. To avoid damaging the equipment, a thermometer (H) is used to monitor the temperature of the solutions. The test is terminated if the temperature exceeds 190° F.

It is desirable for a patch material to have an equal or lower permeability than any concrete it is being placed on top of (i.e. the existing pavement), to avoid the buildup of water at the concrete interface. The permeability test results are shown in Table 11 below. The Denka CSA #20 (Sample 4) and Tetraguard AS20 (Sample 10) were generally less permeable than the control. The patch materials containing Type K cement and Komponent (Samples 2 and 3), on the other hand, were more permeable than the control. The permeability of the Type K cement modified material was, in fact, so high that the 7-day and 28-day tests were terminated to prevent damage to the testing equipment.

Table 11. Permeability Test Results

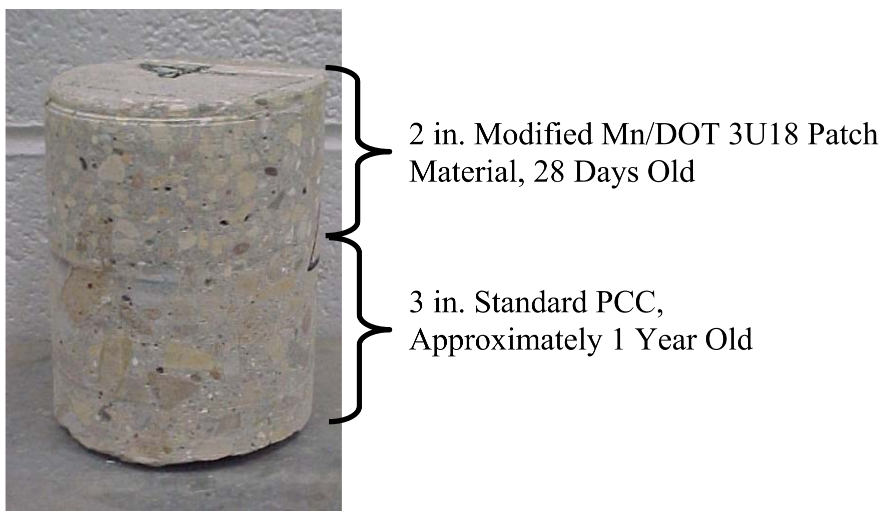
SAMPLE NUMBER	MODIFIED PATCH MATERIAL DESCRIPTIONS	SAMPLE AGE	CHARGE PASSED, Q (Coulombs)	CHLORIDE ION PENETRABILITY
1	Mn/DOT 3U18 **(Control)**	7 DAY	5802	HIGH
		28 DAY	4759	HIGH
		90 DAY	4056	HIGH
2	Mn/DOT 3U18 w/ **Type K Cement**	7 DAY	terminated @ 165 min.	VERY HIGH
		28 DAY	terminated @ 345 min.	VERY HIGH
		90 DAY	5830	HIGH
3	Mn/DOT 3U18 w/ **Komponent**	7 DAY	6597	HIGH
		28 DAY	6455	HIGH
		90 DAY	5897	HIGH
4	Mn/DOT 3U18 w/ **Denka CSA #20**	7 DAY	4815	HIGH
		28 DAY	4478	HIGH
		90 DAY	3644	MODERATE
10	Mn/DOT 3U18 w/ **Tetraguard AS20**	7 DAY	8693	HIGH
		28 DAY	3948	MODERATE
		90 DAY	2853	MODERATE

QUALITATIVE RATINGS	
CHARGE PASSED, Q (Coulombs)	**CHLORIDE ION PENETRABILITY**
Test Terminated (Temperature reached 190° F before 360 min.)	VERY HIGH
>4,000	HIGH
2,000-4,000	MODERATE
1,000-2,000	LOW
100-1,000	VERY LOW
<100	NEGLIGIBLE

- 5.2.6 Concrete-to-Concrete Bond Strength -

To determine the concrete-to-concrete bond strength, spare blocks (12 in. x 12 in. x 3 in.) of 1-year-old standard Portland cement concrete (PCC), were prepared in a similar manner as the concrete pavement slots in a DBR project. The top faces of the blocks were beadblasted, blown clean with compressed air, lightly sprayed with water, and overlaid with 2 inches of the various concrete patch materials. After curing in a moist storage room for 28 days, three 4-inch diameter cores were cut from each block. The cores were 5 inches thick, consisting of 3 inches of old concrete and 2 inches of the patch material (see Figure 17 below).

Figure 17. Core for Iowa Shear Test



The Iowa Shear Test[10] was performed by placing the cores into a shearing device and applying a load at a constant rate of increase (i.e. 50 psi/sec) until the bond between the two types of concrete broke (see Figure 18 on the following page).

[10] Iowa 406-C, Method of Test for Determining the Shearing Strength of Bonded Concrete

Figure 18. Iowa Shear Testing Machine

The concrete core is placed into the shear device on its side, with the bond between the two types of concrete lined up between the two plates (left). While the back (lower) plate remains stationary, the front (upper) plate pulls upward until the bond breaks (right).

The concrete-to-concrete bond strength was calculated by dividing the maximum load at shear failure by the cross-sectional area of the core. The average bond strength of all three cores was calculated for each concrete sample and the results are shown in Table 12 below. All of the modified patch material samples had higher bond strengths than the Mn/DOT 3U18 control. The patch material containing Type K cement had the highest bond strength followed by the Tetraguard AS20, with bond strengths of 1044 and 994 psi, respectively. However, the results of all the materials are acceptable, as a minimum bond strength of 200 psi is generally considered sufficient.

Table 12. Concrete-to-Concrete Bond Strength Test Results

SAMPLE NUMBER	MODIFIED PATCH MATERIAL DESCRIPTIONS	SHEAR STRENGTH (PSI)
1	Mn/DOT 3U18 **(Control)**	827
2	Mn/DOT 3U18 w/ Type K Cement	1044
3	Mn/DOT 3U18 w/ Komponent	875
4	Mn/DOT 3U18 w/ Denka #20 (50.56 lb/yd^3 or 30 kg/m^3)	845
10	Mn/DOT 3U18 w/ Tetraguard AS20	994

- 5.2.7 Phase II Test Results Summary -

The patch materials containing the Type K cement and the Komponent (Samples 2 and 3) failed to meet the testing requirements during Phase II testing, due to poor freeze/thaw durability results. The Type K cement modified material also showed an extremely high permeability rate, which could result in durability problems if used in DBR projects, depending on the permeability of the existing concrete. The Komponent modified material also showed greater shrinkage than the control in the length change test.

At the conclusion of the laboratory testing, the following two patch materials met the testing requirements and showed less shrinkage than the Mn/DOT 3U18 control:

- Sample 4: Mn/DOT 3U18 w/ Denka CSA #20 (50.56 lb/yd^3 or 30 kg/m^3)[11] and
- Sample 10: Mn/DOT 3U18 w/ Tetraguard AS20.

5.3 Phase III Testing

This testing phase was comprised of just one test and evaluated only the concrete curing compounds.

- 5.3.1 Water Retention -

Following the procedure outlined in ASTM C 156, the water retention of concrete coated with a curing compound was measured. As explained in the ASTM Standards, "This test method gives the user a measure of the ability of tested curing materials to impede the escape of moisture from a hydraulic-cement mortar." As mentioned earlier, retaining the moisture in fresh concrete promotes the hydration process and if it is not done effectively, negative effects such as shrinkage and cracking can result.

For this test, 6-inch wide, 12-inch long, 2-inch deep molds were filled with standard mortar. The curing compounds were applied at a rate of 200 ft^2/gal to the 72-in^2 surface area. The initial mass of the standard mortar with the applied curing compound was recorded and then the specimen was placed in a curing cabinet. After 72 hours, the final mass of the mortar and

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[11] In the future, if Denka CSA #20 is unattainable, it is believed that Denka CSA 100R would be an acceptable substitute based on good test results in Phase I.

applied curing compound was determined. The difference in mass, or loss of water, per unit area was calculated for each specimen. The average loss of water was calculated from three specimens of each sample. The results for this test are shown in Table 13 below.

Table 13. Water Retention Test Results

CURING COMPOUND DESCRIPTIONS	WATER LOSS (lb/ft^2)	(kg/m^2)
Sealtight 1600 - White **(CONTROL)**	0.07	0.36
Sealtight 2255 - White (poly-alphamethylstyrene)	0.02	0.11

Although the Sealtight 2255-White showed 69 percent less water loss than the control, both curing compounds met WisDOT specifications (Section 415.2.4) for a maximum water loss of 0.11 lb/ft^2 (0.55 kg/m^2) after 72 hours.[12] The Sealtight 2255-White also met WisDOT's DBR warranty specification requiring a 100 percent poly-alphamethylstyrene resin with a maximum water loss of 0.08 lb/ft^2 (0.40 kg/m^2).

6.0 COST ANALYSIS

To construct a DBR project on 1 lane-mile of 9-inch thick concrete pavement with an average joint spacing of 15 feet and three dowel bars per wheel path, approximately 25 yd^3 of patch material would be required. The material costs of 25 yd^3 of the patch material containing Denka CSA #20 (Sample 4) and Tetraguard AS20 (Sample 10), the two materials that met the testing requirements and showed less shrinkage than the control, are shown in comparison to the Mn/DOT 3U18 control mix in Table 14 on the following page.[13]

[12] Both curing compounds also meet WisDOT specifications (Section 415.2.4) of a minimum reflectance of 60% MgO. Sealtight 1600-White (Control) showed a reflectance of 67% MgO and Sealtight 2255-White showed a reflectance of 70% MgO.

[13] Cost values are for comparison purposes only and are subject to change. The Mn/DOT 3U18 material costs are based on 2001 STH 13 DBR cost data. The additive/admixture costs are based on quotes provided by the manufacturer or supplier in 2003.

Table 14. Cost Comparison

SAMPLE NUMBER	MODIFIED PATCH MATERIAL DESCRIPTIONS	ADDITIVE/ADMIXTURE UNIT COST	ADDITIVE/ADMIXTURE ADDITION RATE	Mn/DOT 3U18 COST/25 yd^3 (1 LANE-MILE)	TOTAL COST/25 yd^3 (1 LANE-MILE)
1	Mn/DOT 3U18 **(Control)**	NA	NA	$1,188.72	$1,188.72
4	Mn/DOT 3U18 w/ Denka #20 (50.56 lb/yd^3 or 30 kg/m^3)	$0.65/lb.	50.56 lb./yd^3	$1,136.26	$1,957.86
10	Mn/DOT 3U18 w/ Tetraguard AS20	$26.00/gal.	1.5 gal./yd^3	$1,188.72	$2,163.72

Note:
Denka CSA #20 is sold in 2000 lb increments and has a shelf life of six months.
(Lidochem, Inc., 20 Village Court, Hazlet, NJ 07730 (732) 888-8000)

Tetraguard AS20 is sold in 55 gal. and 268 gal. containers and has a minimum shelf life of 12 months.
(Degussa Admixtures, Inc., 23700 Chagrin Boulevard, Cleveland, OH 44122 (800) 628-9990)

As expected, the patch materials containing Denka CSA #20 and Tetraguard AS20 are more expensive than the Mn/DOT 3U18 control, increasing the cost of the Mn/DOT 3U18 mix by 65 percent and 82 percent, respectively. The Denka CSA #20 modified mix, however, is approximately 10 percent less expensive than the Tetraguard AS20 modified mix. The most significant cost savings are realized when comparing these two modified patch materials (Sample 4 and Sample 10) to several other rapid setting patch materials currently on the market (see Table 15 below).[14] When compared to the Tamms Speed Crete 2028, the only proprietary patch material used on the STH 13 DBR project that met all of WisDOT's testing requirements, the modified Mn/DOT 3U18 patch materials are less than one-sixth the cost. Furthermore, the modified Mn/DOT 3U18 patch materials are both less than half the cost of the least expensive proprietary mix used on STH 13, which failed WisDOT's freeze/thaw testing.

Table 15. Cost of Proprietary Patch Materials

PROPRIETARY PATCH MATERIALS *(2001 COST DATA FROM STH 13 DBR PROJECT, WOOD COUNTY)*		
PRODUCT NAME	**AGGREGATE EXTENSION**	**COST/25 yd^3 (1 LANE-MILE)**
American Highway Technology Highway DB Retrofit Mortar	100%	$4,519.25
American Highway Technology Highway DB Retrofit Mortar	60%	$5,476.75
ThoRoc 10-60	60%	$9,721.50
Tamms Speed Crete 2028	100%	$13,162.00
Tamms Speed Crete 2028	80%	$14,503.50

[14] The proprietary rapid setting patch material costs are based on 2001 STH 13 DBR cost data.

The Sealtight 2255-White poly-alphamethylstyrene concrete curing compound, at $6.00 per gallon, is three times more expensive than the Sealtight 1600-White (control), at $2.00 per gallon. However, when applied at equal application rates of 200 ft^2/gal., the poly-alphamethylstyrene curing compound experienced less than $^1/_3$ the water loss experienced by the Sealtight 1600-White (control).

7.0 CONCLUSIONS AND RECOMMENDATIONS

WisDOT evaluated several different rapid setting patch materials on a dowel bar retrofit (DBR) rehabilitation project in 2001. Of the patch materials evaluated, only three mixes met all of WisDOT's requirements for rapid set concrete patch materials: one proprietary material (Tamms Speed Crete 2028), tested at two different coarse aggregate extension rates, and the Mn/DOT 3U18 concrete mix (modified with Type III cement in lieu of Type I). The proprietary patch material was approximately 10 times more expensive than the Mn/DOT 3U18 patch material and, within one year, both materials exhibited microcracking and debonding caused by shrinkage.

This study was initiated to test modified Mn/DOT 3U18 mixes in an effort to develop a high performance concrete patch material that is both resistant to shrinkage and cost-effective. A control, consisting of the Mn/DOT 3U18 mix (with Type III cement in lieu of Type I and a specified w/c ratio in lieu of the specified slump) was mixed and tested for comparison purposes. Eleven different products were selected to modify the Mn/DOT 3U18 control mix, including expansive cements or additives, shrinkage reducing admixtures, and saturated lightweight fine aggregates to provide internal curing. The eleven modified patch materials were mixed and tested in the WisDOT Materials Laboratory. The test results showed that two products improved the performance of the Mn/DOT 3U18 patch material by reducing the amount of shrinkage it experienced, without negatively impacting other vital properties required for concrete patch materials: Denka CSA #20 at a dosage rate of 50.56 lb/yd^3 (30 kg/m^3) and Tetraguard AS20. Denka CSA #20 is slightly less expensive than Tetraguard AS20, but both of these products are significantly less expensive when compared to the alternative of using proprietary rapid setting patch materials that are currently on the market.

The patch material containing Denka CSA 100R at a dosage rate of 50.56 lb/yd^3 (30 kg/m^3) showed similar test results to the patch material containing Denka CSA #20 at a dosage rate of 50.56 lb/yd^3 (30 kg/m^3) in Phase I testing. This is likely due to the fact that both products have a similar composition, as Denka CSA 100R is comprised of Denka CSA #20 with an additional agent to reduce the heat of hydration. Since the Denka CSA #20 produced slightly better results in Phase I and showed favorable results in Phase II, it is the preferred Denka product. However, it is believed that Denka CSA 100R would perform satisfactorily and would be an acceptable substitute if Denka CSA #20 were not available.

Two concrete curing compounds were also evaluated for their ability to prevent moisture loss from the surface of the patch materials, which leads to concrete shrinkage. Test results showed that the Sealtight 2255-White, a poly-alphamethylstyrene-based concrete curing compound, was much more effective at retaining moisture in a concrete mix than Sealtight 1600-White, a water-based, wax-based concrete curing compound, but it is also three times more expensive.

As previously stated, the sample containing Hydrocure did not advance to Phase II testing due to poor test results from the change in height test of Phase I. However, at the request of the manufacturer, some additional testing was conducted on a patch material containing a higher proportion of Hydrocure, to further evaluate the internal curing technique using saturated lightweight fine aggregate (see Appendix C). When a higher proportion (50 percent) of the patch material's sand was replaced with saturated lightweight fine aggregate (as opposed to approximately 20 percent in Phase I), the patch material exhibited less shrinkage than the control.

Based on the results of this study, the following recommendations are made:

- Denka CSA #20 and Tetraguard AS20 modified MnDOT 3U18 patch materials should be used in separate test sections in an upcoming dowel bar retrofit project so their field performances can be evaluated.

- Sealtight 2255-White (the poly-alphamethylstyrene-based concrete curing compound) should also be incorporated into the same DBR project for comparisons with Sealtight 1600-White (the water-based, wax-based curing compound), to evaluate their performances and cost-effectiveness.
- If the field performances of the modified concrete mixes are successful[15], it will be recommended that the WisDOT dowel bar retrofit warranty be changed to 3,000 psi at 24 hours, to allow the use of a modified Mn/DOT 3U18 patch material on DBR projects with at least 24-hour lane closures.
- If the Sealtight 2255-White poly-alphamethylstyrene-based concrete curing compound does not prove to be cost-effective, modifications to WisDOT's DBR warranty specification will be recommended.
- Further experimentation using saturated LWFA to prevent shrinkage should be conducted. Although the sticky consistency of the concrete mixes made with LWFA would make it difficult to use in DBR projects, it might work well for other applications.

8.0 IMPLEMENTATION

The WisDOT Technology Advancement Unit will solicit the transportation districts for a DBR project scheduled for construction in 2005. Test sections evaluating the Mn/DOT 3U18 patch material containing Denka CSA #20 (Sample 4 from this study) and Tetraguard AS20 (Sample 10 from this study) will be installed on this site and the proprietary patch material used for the remainder of the project will be used as the control. The Sealtight 2255-White concrete curing compound will also be tested on this project to further evaluate its performance, with the Sealtight 1600-White used as the control. The combinations of patch materials and curing compounds will result in a minimum of three test sections, with the Sealtight 1600-White applied in one wheelpath and the Sealtight 2255-White applied in the other wheelpath of each test section. If

[15] It is a concern that, initially after construction, thermal conditions might cause the concrete slabs and steel dowels to apply stresses to the patch material in the DBR slots. If the patch material cannot gain strength rapidly enough to resist these stresses, it is likely to become damaged.

feasible, all test sections will be replicated with the curing compounds in alternate wheelpaths.

The proposed test sections are shown in Table 16 below.

Table 16. Projected Test Sections

TEST SECTIONS	Denka CSA #20	Tetraguard AS20	Proprietary Control
Sealtight 1600-White (LWP) **Sealtight 2255-White (RWP)**	Test Section 1A	Test Section 2A	Test Section 3A

REPLICATED TEST SECTIONS	Denka CSA #20	Tetraguard AS20	Proprietary Control
Sealtight 2255-White (LWP) **Sealtight 1600-White (RWP)**	Test Section 1B	Test Section 2B	Test Section 3B

The field investigation will be monitored for one year, at which time any material shrinkage and resultant cracking or debonding will be observable. If applicable, changes to WisDOT's DBR warranty specification will be made.

If resources permit, additional laboratory testing of Solite and Hydrocure saturated lightweight fine aggregates, at a 50% sand replacement rate, will be conducted in WisDOT's Materials Laboratory. Testing should include, at a minimum, compressive strength, length change, freeze-thaw durability, and permeability.

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APPENDIX A:
PHASE I PATCH MATERIAL MIX DESIGNS
AND TEST RESULTS

Mn/DOT 3U18 (Control)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 1 ATTEMPT: 1ST
SAMPLE DESCRIPTION: Mn/DOT 3U18 (CONTROL)
WATER/CEMENT RATIO: 0.339
DATE MIXED: 2/6/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 15.27 lb	
AIR ENTRAINING ADMIXTURE: 18 mL	DARAVAIR 1400 (GRACE)
OTHER: NA	

INITIAL TESTING	BATCH STATUS
SLUMP: NOT TESTED	REJECTED
UNIT WEIGHT: NOT TESTED	FOR PHASE I TESTING
AIR CONTENT: NOT TESTED	(TOO DRY/STIFF)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 1 ATTEMPT: 2ND (WATER INCREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 (CONTROL)
WATER/CEMENT RATIO: 0.384
DATE MIXED: 2/6/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.27 lb	
AIR ENTRAINING ADMIXTURE: 18 mL	DARAVAIR 1400 (GRACE)
OTHER: NA	

INITIAL TESTING	BATCH STATUS
SLUMP: 2.75 in.	REJECTED
UNIT WEIGHT: 144.47 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: 3.10%	(LOW AIR)

ADDITIONAL TESTING	RESULTS
COMPRESSIVE STRENGTH - 7 DAYS	7425 psi

Mn/DOT 3U18 (Control) (Continued)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 1 ATTEMPT: 3^{RD} (AEA INCREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 (CONTROL)
WATER/CEMENT RATIO: 0.384
DATE MIXED: 2/6/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.27 lb	
AIR ENTRAINING ADMIXTURE: 28 mL	DARAVAIR 1400 (GRACE)
OTHER: NA	

INITIAL TESTING	BATCH STATUS
SLUMP: 0.25 in.	REJECTED
UNIT WEIGHT: NOT TESTED	FOR PHASE I TESTING
AIR CONTENT: 2.85%	(LOW AIR)

Mn/DOT 3U18 (Control) (Continued)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 1 ATTEMPT: 4[TH] (WATER & AEA INCREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 (CONTROL)
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/6/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 35 mL	DARAVAIR 1400 (GRACE)
OTHER: NA	

INITIAL TESTING	BATCH STATUS
SLUMP: 2.25 in.	ACCEPTED FOR PHASE I TESTING
UNIT WEIGHT: 143.59 lb/ft^3	
AIR CONTENT: 4.50%	

PHASE I TESTING	RESULTS
TIME OF SET	179.29 min.
CHANGE IN HEIGHT - INITIAL READING	0.2058 in.
1 DAY	0.2334 in., -0.460% change (shrink.)
3 DAYS	0.2339 in., -0.469% change (shrink.)
7 DAYS	0.2346 in., -0.481% change (shrink.)
COMPRESSIVE STRENGTH - 4 HOURS	70 psi
6 HOURS	240 psi
8 HOURS	670 psi
1 DAY	4425 psi
3 DAYS	6755 psi
7 DAYS	7210 psi
28 DAYS	6885 psi

Type K Cement

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 2 ATTEMPT: 1^{ST}
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Type K Cement
WATER/CEMENT RATIO: 0.420
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE K (CTS CEMENT)
DESIGN WATER: 18.90 lb	
AIR ENTRAINING ADMIXTURE: 80 mL	DARAVAIR 1400 (GRACE)
OTHER: NA	

INITIAL TESTING	BATCH STATUS
SLUMP: NOT TESTED*	REJECTED
UNIT WEIGHT: 133.43 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: > 10.00% (off the meter)	(HIGH AIR)

* The patch material consistency was too wet to attempt measuring the slump.

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 2 ATTEMPT: 2^{ND} (AEA DECREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Type K Cement
WATER/CEMENT RATIO: 0.420
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE K (CTS CEMENT)
DESIGN WATER: 18.90 lb	
AIR ENTRAINING ADMIXTURE: 40 mL	DARAVAIR 1400 (GRACE)
OTHER: NA	

INITIAL TESTING	BATCH STATUS
SLUMP: NOT TESTED*	REJECTED
UNIT WEIGHT: 131.31 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: > 10.00% (off the meter)	(HIGH AIR)

* The patch material consistency was too wet to attempt measuring the slump.

Type K Cement (Continued)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 2 ATTEMPT: 3^{RD} (AEA DECREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Type K Cement
WATER/CEMENT RATIO: 0.420
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE K (CTS CEMENT)
DESIGN WATER: 18.90 lb	
AIR ENTRAINING ADMIXTURE: 10 mL	DARAVAIR 1400 (GRACE)
OTHER: NA	

INITIAL TESTING	BATCH STATUS
SLUMP: NOT TESTED*	REJECTED
UNIT WEIGHT: 135.12 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: 8.60%	(HIGH AIR)

* The patch material consistency was too wet to attempt measuring the slump.

Type K Cement (Continued)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 2 ATTEMPT: 4[TH] (AEA DECREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Type K Cement
WATER/CEMENT RATIO: 0.420
DATE MIXED: 6/10/2003 (Delayed from earlier attempts - awaiting more material)

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE K (CTS CEMENT)
DESIGN WATER: 18.90 lb	
AIR ENTRAINING ADMIXTURE: 6 mL	DARAVAIR 1400 (GRACE)
OTHER: NA	

INITIAL TESTING	BATCH STATUS
SLUMP: 8.75 in.	ACCEPTED
UNIT WEIGHT: 141.07 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: 5.00%	

PHASE I TESTING	RESULTS
TIME OF SET	197.81 min.
CHANGE IN HEIGHT - INITIAL READING	0.3193 in.
1 DAY	0.2681 in., 0.852% change (expan.)
3 DAYS	0.2668 in., 0.875% change (expan.)
7 DAYS	0.2893 in., 0.500% change (expan.)
COMPRESSIVE STRENGTH - 8 HOURS	255 psi
1 DAY	1395 psi
3 DAYS	2410 psi
7 DAYS	3385 psi
28 DAYS	5375 psi
56 DAYS	6210 psi
90 DAYS	6950 psi

Komponent

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 3 ATTEMPT: 1ST
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Komponent
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/6/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 38.26 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 40 mL	DARAVAIR 1400 (GRACE)
OTHER: 6.75 lb	KOMPONENT

INITIAL TESTING	BATCH STATUS
SLUMP: 3.00 in.	ACCEPTED FOR PHASE I TESTING
UNIT WEIGHT: 142.51 lb/ft^3	
AIR CONTENT: 4.80%	

PHASE I TESTING	RESULTS
TIME OF SET	204.34 min.
CHANGE IN HEIGHT - INITIAL READING	0.1933 in.
1 DAY	0.1890 in., 0.071% change (expan.)
3 DAYS	0.1895 in., 0.063% change (expan.)
7 DAYS	0.1905 in., 0.046% change (expan.)
COMPRESSIVE STRENGTH - 4 HOURS	45 psi
6 HOURS	155 psi
8 HOURS	545 psi
1 DAY	2945 psi
3 DAYS	4200 psi
7 DAYS	5170 psi
28 DAYS	5175 psi

Denka CSA #20 (50.56 lb/yd^3 or 30 kg/m^3)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 4 ATTEMPT: 1ST
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Denka CSA #20 (50.56 lb/yd^3 or 30 kg/m^3)
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/18/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 42.20 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 50 mL	DARAVAIR 1400 (GRACE)
OTHER: 2.81 lb	DENKA CSA #20

INITIAL TESTING	BATCH STATUS
SLUMP: 2.50 in.	ACCEPTED
UNIT WEIGHT: 142.35 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: 5.00%	

PHASE I TESTING	RESULTS
TIME OF SET	177.00 min.
CHANGE IN HEIGHT - INITIAL READING	0.2715 in.
1 DAY	0.2706 in., 0.015% change (expan.)
3 DAYS	0.2713 in., 0.004% change (expan.)
7 DAYS	0.2716 in., -0.002% change (shrink.)
COMPRESSIVE STRENGTH - 4 HOURS	50 psi
6 HOURS	305 psi
8 HOURS	895 psi
1 DAY	4215 psi
3 DAYS	5020 psi
7 DAYS	5555 psi
28 DAYS	6530 psi

Denka CSA #20 (42.14 lb/yd^3 or 25 kg/m^3)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 5 ATTEMPT: 1ST
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Denka CSA #20 (42.14 lb/yd^3 or 25 kg/m^3)
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/18/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 42.67 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 55 mL	DARAVAIR 1400 (GRACE)
OTHER: 2.35 lb	DENKA CSA #20

INITIAL TESTING	BATCH STATUS
SLUMP: 3.25 in.	ACCEPTED
UNIT WEIGHT: 141.79 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: 5.00%	

PHASE I TESTING	RESULTS
TIME OF SET	197.00 min.
CHANGE IN HEIGHT - INITIAL READING	0.2904 in.
1 DAY	0.2936 in., -0.054% change (shrink.)
3 DAYS	0.2946 in., -0.071% change (shrink.)
7 DAYS	0.2943 in., -0.065% change (shrink.)
COMPRESSIVE STRENGTH - 4 HOURS	55 psi
6 HOURS	235 psi
8 HOURS	730 psi
1 DAY	3945 psi
3 DAYS	5490 psi
7 DAYS	5670 psi
28 DAYS	6180 psi

Denka CSA 100R (50.56 lb/yd^3 or 30 kg/m^3)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 6 ATTEMPT: 1ST
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Denka CSA 100R (50.56 lb/yd^3 or 30 kg/m^3)
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/18/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 42.20 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 60 mL	DARAVAIR 1400 (GRACE)
OTHER: 2.81 lb	DENKA CSA 100R

INITIAL TESTING	BATCH STATUS
SLUMP: 2.00 in.	ACCEPTED
UNIT WEIGHT: 143.33 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: 4.40%	

PHASE I TESTING	RESULTS
TIME OF SET	179.00 min.
CHANGE IN HEIGHT - INITIAL READING	0.2779 in.
1 DAY	0.2776 in., 0.004% change (expan.)
3 DAYS	0.2799 in., -0.033% change (shrink.)
7 DAYS	0.2794 in., -0.025% change (shrink.)
COMPRESSIVE STRENGTH - 4 HOURS	70 psi
6 HOURS	310 psi
8 HOURS	1070 psi
1 DAY	4225 psi
3 DAYS	6050 psi
7 DAYS	6000 psi
28 DAYS	6850 psi

Denka CSA 100R (42.14 lb/yd^3 or 25 kg/m^3)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 7 ATTEMPT: 1ST
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Denka CSA 100R (42.14 lb/yd^3 or 25 kg/m^3)
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/18/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 42.67 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 70 mL	DARAVAIR 1400 (GRACE)
OTHER: 2.35 lb	DENKA CSA 100R

INITIAL TESTING	BATCH STATUS
SLUMP: 1.50 in.	ACCEPTED
UNIT WEIGHT: 142.97 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: 4.30%	

PHASE I TESTING	RESULTS
TIME OF SET	197.00 min.
CHANGE IN HEIGHT - INITIAL READING	0.2731 in.
1 DAY	0.2796 in., -0.108% change (shrink.)
3 DAYS	0.2795 in., -0.106% change (shrink.)
7 DAYS	0.2800 in., -0.115% change (shrink.)
COMPRESSIVE STRENGTH - 4 HOURS	55 psi
6 HOURS	195 psi
8 HOURS	885 psi
1 DAY	4150 psi
3 DAYS	6335 psi
7 DAYS	6145 psi
28 DAYS	6635 psi

Peramin SRA330

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 8 ATTEMPT: 1^{ST}
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Peramin SRA330
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 60 mL	PERAMIN L (PERSTORP)
OTHER: 0.90 lb	PERAMIN SRA330

INITIAL TESTING	BATCH STATUS
SLUMP: NOT TESTED*	REJECTED FOR PHASE I TESTING (LOW AIR)
UNIT WEIGHT: 145.29 lb/ft^3	
AIR CONTENT: 2.60%	

* The patch material consistency was too dry to attempt measuring the slump.

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 8 ATTEMPT: 2^{ND} (AEA INCREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Peramin SRA330
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 180 mL	PERAMIN L (PERSTORP)
OTHER: 0.90 lb	PERAMIN SRA330

INITIAL TESTING	BATCH STATUS
SLUMP: NOT TESTED*	REJECTED FOR PHASE I TESTING (LOW AIR)
UNIT WEIGHT: 144.83 lb/ft^3	
AIR CONTENT: 2.80%	

* The patch material consistency was too dry to attempt measuring the slump.

Peramin SRA330 (Continued)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 8 ATTEMPT: 3RD (NEW AEA)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Peramin SRA330
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 200 mL	MICRO AIR (MBT)
OTHER: 0.90 lb	PERAMIN SRA330

INITIAL TESTING	BATCH STATUS
SLUMP: NOT TESTED*	REJECTED FOR PHASE I TESTING (LOW AIR)
UNIT WEIGHT: 144.11 lb/ft^3	
AIR CONTENT: 3.60%	

* The patch material consistency was too dry to attempt measuring the slump.

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 8 ATTEMPT: 4TH (NEW AEA INCREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Peramin SRA330
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 300 mL	MICRO AIR (MBT)
OTHER: 0.90 lb	PERAMIN SRA330

INITIAL TESTING	BATCH STATUS
SLUMP: NOT TESTED*	REJECTED FOR PHASE I TESTING (LOW AIR)
UNIT WEIGHT: 144.13 lb/ft^3	
AIR CONTENT: 3.60%	

* The patch material consistency was too dry to attempt measuring the slump.

Peramin SRA330 (Continued)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 8 ATTEMPT: 5TH (NEW AEA INCREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Peramin SRA330
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LA FARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 500 mL	MICRO AIR (MBT)
OTHER: 0.90 lb	PERAMIN SRA330

INITIAL TESTING	BATCH STATUS
SLUMP: NOT TESTED*	REJECTED
UNIT WEIGHT: 142.85 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: 3.80%	(LOW AIR)

* The patch material consistency was too dry to attempt measuring the slump.

<u>NOTE:</u> The Peramin SRA330 product was eliminated from this study after five failed attempts, using two different air entraining admixtures, to meet the design parameters established for this research study.

Eclipse Plus

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 9 ATTEMPT: 1^{ST}
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Eclipse Plus
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 80 mL	DAREX II AEA (GRACE)
OTHER: 0.58 lb	ECLIPSE PLUS

INITIAL TESTING	BATCH STATUS
SLUMP: NOT TESTED*	REJECTED FOR PHASE I TESTING (LOW AIR)
UNIT WEIGHT: 157.44 lb/ft^3	
AIR CONTENT: 3.10%	

* The patch material consistency was too dry to attempt measuring the slump.

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 9 ATTEMPT: 2^{ND} (AEA INCREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Eclipse Plus
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 120 mL	DAREX II AEA (GRACE)
OTHER: 0.58 lb	ECLIPSE PLUS

INITIAL TESTING	BATCH STATUS
SLUMP: NOT TESTED*	REJECTED FOR PHASE I TESTING (LOW AIR)
UNIT WEIGHT: 145.15 lb/ft^3	
AIR CONTENT: 3.30%	

* The patch material consistency was too dry to attempt measuring the slump.

Eclipse Plus (Continued)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 9 ATTEMPT: 3RD (AEA INCREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Eclipse Plus
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LA FARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 300 mL	DAREX II AEA (GRACE)
OTHER: 0.58 lb	ECLIPSE PLUS

INITIAL TESTING	BATCH STATUS
SLUMP: 0.25 in.	REJECTED
UNIT WEIGHT: 145.13 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: 3.50%	(LOW AIR)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 9 ATTEMPT: 4TH (NEW AEA)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Eclipse Plus
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LA FARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 140 mL	MICRO AIR (MBT)
OTHER: 0.58 lb	ECLIPSE PLUS

INITIAL TESTING	BATCH STATUS
SLUMP: NOT TESTED*	REJECTED
UNIT WEIGHT: 145.19 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: 3.80%	(LOW AIR)

* The patch material consistency was too dry to attempt measuring the slump.

Eclipse Plus (Continued)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 9 ATTEMPT: 5^{TH} (NEW AEA INCREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Eclipse Plus
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 200 mL	MICRO AIR (MBT)
OTHER: 0.58 lb	ECLIPSE PLUS

INITIAL TESTING	BATCH STATUS
SLUMP: NOT TESTED*	REJECTED
UNIT WEIGHT: 145.01 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: 3.40%	(LOW AIR)

* The patch material consistency was too dry to attempt measuring the slump.

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 9 ATTEMPT: 6^{TH} (NEW AEA INCREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Eclipse Plus
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 300 mL	MICRO AIR (MBT)
OTHER: 0.58 lb	ECLIPSE PLUS

INITIAL TESTING	BATCH STATUS
SLUMP: NOT TESTED*	REJECTED
UNIT WEIGHT: 145.15 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: 3.40%	(LOW AIR)

* The patch material consistency was too dry to attempt measuring the slump.

NOTE: The Eclipse Plus product was eliminated from this study after six failed attempts, using two different air entraining admixtures, to meet the design parameters established for this research study.

Tetraguard AS20

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 10 ATTEMPT: 1ST
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Tetraguard AS20
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/27/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 100 mL	MICRO AIR (MBT)
OTHER: 0.69 lb	TETRAGUARD AS20

INITIAL TESTING	BATCH STATUS
SLUMP: 1.00 in.	ACCEPTED
UNIT WEIGHT: 144.11 lb/ft^3	FOR PHASE I TESTING
AIR CONTENT: 4.00%	

PHASE I TESTING	RESULTS
TIME OF SET	195.32 min.
CHANGE IN HEIGHT - INITIAL READING	0.2895 in.
1 DAY	0.2968 in., -0.121% change (shrink.)
3 DAYS	0.2966 in., -0.119% change (shrink.)
7 DAYS	0.2973 in., -0.129% change (shrink.)
COMPRESSIVE STRENGTH - 4 HOURS	45 psi
6 HOURS	160 psi
8 HOURS	695 psi
1 DAY	3545 psi
3 DAYS	4850 psi
7 DAYS	5490 psi
28 DAYS	6590 psi

Solite

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 11 ATTEMPT: 1^{ST}
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Solite (LWFA)
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/6/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 56.02 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 43 mL	DARAVAIR 1400 (GRACE)
OTHER: 15.54 lb	SOLITE (19% moisture content)

INITIAL TESTING	BATCH STATUS
SLUMP: 0.25 in.	REJECTED
UNIT WEIGHT: NOT TESTED	FOR PHASE I TESTING
AIR CONTENT: 3.60%	(LOW AIR)

Solite (Continued)

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 11 ATTEMPT: 2ND (AEA INCREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Solite (LWFA)
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/6/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 56.02 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 60 mL	DARAVAIR 1400 (GRACE)
OTHER: 15.54 lb	SOLITE (19% moisture content)

INITIAL TESTING	BATCH STATUS
SLUMP: 0.00 in.	ACCEPTED FOR PHASE I TESTING
UNIT WEIGHT: 141.31 lb/ft^3	
AIR CONTENT: 4.00%	

PHASE I TESTING	RESULTS
TIME OF SET	211.48 min.
CHANGE IN HEIGHT - INITIAL READING	0.2040 in.
1 DAY	0.2300 in., -0.433% change (shrink.)
3 DAYS	0.2313 in., -0.456% change (shrink.)
7 DAYS	0.2335 in., -0.492% change (shrink.)
COMPRESSIVE STRENGTH - 4 HOURS	45 psi
6 HOURS	155 psi
8 HOURS	680 psi
1 DAY	3715 psi
3 DAYS	6045 psi
7 DAYS	6965 psi
28 DAYS	6165 psi

Hydrocure

PHASE I: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 12 ATTEMPT: 1ST
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Hydrocure (LWFA)
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/6/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 58.14 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 70 mL	DARAVAIR 1400 (GRACE)
OTHER: 13.43 lb	HYDROCURE (22% moisture content)

INITIAL TESTING	BATCH STATUS
SLUMP: 0.25 in.	ACCEPTED FOR PHASE I TESTING
UNIT WEIGHT: 141.63 lb/ft^3	
AIR CONTENT: 4.00%	

PHASE I TESTING	RESULTS
TIME OF SET	221.75 min.
CHANGE IN HEIGHT - INITIAL READING	0.2030 in.
1 DAY	0.2416 in., -0.644% change (shrink.)
3 DAYS	0.2424 in., -0.656% change (shrink.)
7 DAYS	0.2426 in., -0.660% change (shrink.)
COMPRESSIVE STRENGTH - 4 HOURS	35 psi
6 HOURS	185 psi
8 HOURS	235 psi
1 DAY	4425 psi
3 DAYS	6535 psi
7 DAYS	7235 psi
28 DAYS	6590 psi

APPENDIX B:
PHASE II PATCH MATERIAL MIX DESIGNS
AND TEST RESULTS

Note 1: The mix designs for Phase II testing remained the same as in Phase I, with the exception of the amount of air entraining admixture (AEA) used. In Phase II, the amount of AEA was adjusted in an attempt to achieve an air content closer to 6 percent.

Note 2: In Phase II, two batches of each patch material were mixed and the batch with the best air content was selected to complete Phase II testing.

Mn/DOT 3U18 (Control)

PHASE II: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 1 ATTEMPT: 1ST
SAMPLE DESCRIPTION: Mn/DOT 3U18 (CONTROL)
WATER/CEMENT RATIO: 0.395
DATE MIXED: 4/22/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 50 mL	DARAVAIR 1400 (GRACE)
OTHER: NA	

INITIAL TESTING	BATCH STATUS
SLUMP: 1.50 in.	REJECTED
UNIT WEIGHT: 143.71 lb/ft^3	FOR PHASE II TESTING
AIR CONTENT: 4.10%	(LOW AIR)

ADDITIONAL TESTING	RESULTS
COMPRESSIVE STRENGTH - 1 DAY	4495 psi
3 DAYS	5375 psi
7 DAYS	5950 psi
28 DAYS	6390 psi
56 DAYS	7990 psi
90 DAYS	8825 psi

Mn/DOT 3U18 (Control) (Continued)

PHASE II: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 1 ATTEMPT: 2^{ND} (AEA INCREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 (CONTROL)
WATER/CEMENT RATIO: 0.395
DATE MIXED: 4/22/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 70 mL	DARAVAIR 1400 (GRACE)
OTHER: NA	

INITIAL TESTING	BATCH STATUS
SLUMP: 1.75 in.	ACCEPTED
UNIT WEIGHT: 143.53 lb/ft^3	FOR PHASE II TESTING
AIR CONTENT: 4.60%	

PHASE II TESTING	RESULTS
COMPRESSIVE STRENGTH - 1 DAY	4545 psi
3 DAYS	5325 psi
7 DAYS	6180 psi
LENGTH CHANGE - 3 DAYS	-0.00642% change (shrink.)
7 DAYS	-0.01500% change (shrink.)
28 DAYS	-0.02842% change (shrink.)
56 DAYS	-0.03767% change (shrink.)
90 DAYS	-0.03958% change (shrink.)
FREEZE/THAW DURABILITY - 101 CYC.	0.00% loss in mass
200 CYC.	0.60% loss in mass
300 CYC.	1.70% loss in mass
PERMEABILITY - 7 DAYS	5802 C of charge passed (high)
28 DAYS	4759 C of charge passed (high)
90 DAYS	4056 C of charge passed (high)
BOND STRENGTH	827 psi

Type K Cement

PHASE II: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 2 ATTEMPT: 1ST
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Type K Cement
WATER/CEMENT RATIO: 0.420
DATE MIXED: 6/10/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE K (CTS CEMENT)
DESIGN WATER: 18.90 lb	
AIR ENTRAINING ADMIXTURE: 6 mL	DARAVAIR 1400 (GRACE)
OTHER: NA	

INITIAL TESTING	BATCH STATUS
SLUMP: 8.75 in.	REJECTED FOR ADDITIONAL TESTING (LOW AIR)
UNIT WEIGHT: 141.07 lb/ft^3	
AIR CONTENT: 5.00%	

ADDITIONAL TESTING	RESULTS
COMPRESSIVE STRENGTH - 8 HOURS	255 psi
1 DAY	1395 psi
3 DAYS	2410 psi
7 DAYS	3385 psi
28 DAYS	5375 psi
56 DAYS	6210 psi
90 DAYS	6950 psi

Type K Cement (Continued)

PHASE II: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 2 ATTEMPT: 2^{ND}
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Type K Cement
WATER/CEMENT RATIO: 0.420
DATE MIXED: 6/10/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE K (CTS CEMENT)
DESIGN WATER: 18.90 lb	
AIR ENTRAINING ADMIXTURE: 5 mL	DARAVAIR 1400 (GRACE)
OTHER: NA	

INITIAL TESTING	BATCH STATUS
SLUMP: 7.75 in.	ACCEPTED FOR ADDITIONAL TESTING
UNIT WEIGHT: 141.33 lb/ft^3	
AIR CONTENT: 5.20%	

ADDITIONAL TESTING	RESULTS
COMPRESSIVE STRENGTH - 1 DAY	1680 psi
3 DAYS	2700 psi
7 DAYS	3480 psi
LENGTH CHANGE - 3 DAYS	0.00158% change (expan.)
7 DAYS	-0.00383% change (shrink.)
28 DAYS	-0.02358% change (shrink.)
56 DAYS	-0.03500% change (shrink.)
90 DAYS	-0.03867% change (shrink.)
FREEZE/THAW DURABILITY - 101 CYC.	6.50% loss in mass
200 CYC.	10.20% loss in mass
300 CYC.	15.80% loss in mass
PERMEABILITY - 7 DAYS	terminated at 165 min. (very high)
28 DAYS	terminated at 345 min. (very high)
90 DAYS	5830 C of charge passed (high)
BOND STRENGTH	1044 psi

Komponent

PHASE II: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 3 ATTEMPT: 1ST
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Komponent
WATER/CEMENT RATIO: 0.395
DATE MIXED: 4/24/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 38.26 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 55 mL	DARAVAIR 1400 (GRACE)
OTHER: 6.75 lb	KOMPONENT

INITIAL TESTING	BATCH STATUS
SLUMP: 1.50 in.	REJECTED
UNIT WEIGHT: 142.35 lb/ft^3	FOR PHASE II TESTING
AIR CONTENT: 4.60%	(LOW AIR)

ADDITIONAL TESTING	RESULTS
COMPRESSIVE STRENGTH - 1 DAY	3155 psi
3 DAYS	4030 psi
7 DAYS	5082 psi
28 DAYS	6580 psi
56 DAYS	7300 psi
90 DAYS	8225 psi

Komponent (Continued)

PHASE II: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 3 ATTEMPT: 2ND (AEA INCREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Komponent
WATER/CEMENT RATIO: 0.395
DATE MIXED: 4/24/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 38.26 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 70 mL	DARAVAIR 1400 (GRACE)
OTHER: 6.75 lb	KOMPONENT

INITIAL TESTING	BATCH STATUS
SLUMP: 1.75 in.	ACCEPTED
UNIT WEIGHT: 142.03 lb/ft^3	FOR PHASE II TESTING
AIR CONTENT: 4.80%	

PHASE II TESTING	RESULTS
COMPRESSIVE STRENGTH - 1 DAY	3175 psi
3 DAYS	4410 psi
7 DAYS	4654 psi
LENGTH CHANGE - 3 DAYS	-0.00125% change (shrink.)
7 DAYS	-0.00517% change (shrink.)
28 DAYS	-0.02442% change (shrink.)
56 DAYS	-0.03617% change (shrink.)
90 DAYS	-0.04083% change (shrink.)
FREEZE/THAW DURABILITY - 101 CYC.	0.70% loss in mass
200 CYC.	9.50% loss in mass
300 CYC.	25.50% loss in mass
PERMEABILITY - 7 DAYS	6597 C of charge passed (high)
28 DAYS	6455 C of charge passed (high)
90 DAYS	5897 C of charge passed (high)
BOND STRENGTH	875 psi

Denka CSA #20 (50.56 lb/yd^3 or 30 kg/m^3)

PHASE II: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 4 ATTEMPT: 1ST
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Denka CSA #20 (50.56 lb/yd^3 or 30 kg/m^3)
WATER/CEMENT RATIO: 0.395
DATE MIXED: 4/24/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 42.20 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 70 mL	DARAVAIR 1400 (GRACE)
OTHER: 2.81 lb	DENKA CSA #20

INITIAL TESTING	BATCH STATUS
SLUMP: 2.00 in.	REJECTED
UNIT WEIGHT: 142.59 lb/ft^3	FOR PHASE II TESTING
AIR CONTENT: 4.80%	(LOW AIR)

ADDITIONAL TESTING	RESULTS
COMPRESSIVE STRENGTH - 1 DAY	4140 psi
3 DAYS	5155 psi
7 DAYS	6901 psi
28 DAYS	6860 psi
56 DAYS	8010 psi
90 DAYS	8065 psi

Denka CSA #20 (50.56 lb/yd^3 or 30 kg/m^3) (Continued)

PHASE II: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 4 ATTEMPT: 2ND
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Denka CSA #20 (50.56 lb/yd^3 or 30 kg/m^3)
WATER/CEMENT RATIO: 0.395
DATE MIXED: 4/24/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 42.20 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 65 mL	DARAVAIR 1400 (GRACE)
OTHER: 2.81 lb	DENKA CSA #20

INITIAL TESTING	BATCH STATUS
SLUMP: 2.25 in.	ACCEPTED
UNIT WEIGHT: 142.71 lb/ft^3	FOR PHASE II TESTING
AIR CONTENT: 5.00%	

PHASE II TESTING	RESULTS
COMPRESSIVE STRENGTH - 1 DAY	3955 psi
3 DAYS	5965 psi
7 DAYS	6790 psi
LENGTH CHANGE - 3 DAYS	-0.00500% change (shrink.)
7 DAYS	-0.01292% change (shrink.)
28 DAYS	-0.02858% change (shrink.)
56 DAYS	-0.03283% change (shrink.)
90 DAYS	-0.03667% change (shrink.)
FREEZE/THAW DURABILITY - 101 CYC.	-0.10% loss in mass*
200 CYC.	0.70% loss in mass
300 CYC.	5.40% loss in mass
PERMEABILITY - 7 DAYS	4815 C of charge passed (high)
28 DAYS	4478 C of charge passed (high)
90 DAYS	3644 C of charge passed (moderate)
BOND STRENGTH	845 psi

* A negative loss in mass, or a gain in mass, is due to hydration and chloride ion gains.

Tetraguard AS20

PHASE II: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 10 ATTEMPT: 1ST
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Tetraguard AS20
WATER/CEMENT RATIO: 0.395
DATE MIXED: 4/22/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 150 mL	MICRO AIR (MBT)
OTHER: 0.69 lb	TETRAGUARD AS20

INITIAL TESTING	BATCH STATUS
SLUMP: 0.50 in.	REJECTED
UNIT WEIGHT: 143.19 lb/ft^3	FOR PHASE II TESTING
AIR CONTENT: 4.70%	(LOW AIR)

ADDITIONAL TESTING	RESULTS
COMPRESSIVE STRENGTH - 1 DAY	4130 psi
3 DAYS	4925 psi
7 DAYS	5885 psi
28 DAYS	6110 psi
56 DAYS	7255 psi
90 DAYS	8785 psi

Tetraguard AS20 (Continued)

PHASE II: MIX DESIGNS AND TEST RESULTS

SAMPLE NUMBER: 10 ATTEMPT: 2^{ND} (AEA INCREASED)
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Tetraguard AS20
WATER/CEMENT RATIO: 0.395
DATE MIXED: 4/22/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 71.57 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 200 mL	MICRO AIR (MBT)
OTHER: 0.69 lb	TETRAGUARD AS20

INITIAL TESTING	BATCH STATUS
SLUMP: 0.25 in.	ACCEPTED
UNIT WEIGHT: 142.81 lb/ft^3	FOR PHASE II TESTING
AIR CONTENT: 5.00%	

PHASE II TESTING	RESULTS
COMPRESSIVE STRENGTH - 1 DAY	3970 psi
3 DAYS	5095 psi
7 DAYS	5120 psi
LENGTH CHANGE - 3 DAYS	0.00350% change (expan.)
7 DAYS	-0.00325% change (shrink.)
28 DAYS	-0.01383% change (shrink.)
56 DAYS	-0.02133% change (shrink.)
90 DAYS	-0.02300% change (shrink.)
FREEZE/THAW DURABILITY - 101 CYC.	1.40% loss in mass
200 CYC.	4.20% loss in mass
300 CYC.	9.90% loss in mass
PERMEABILITY - 7 DAYS	8693 C of charge passed (high)
28 DAYS	3948 C of charge passed (moderate)
90 DAYS	2853 C of charge passed (moderate)
BOND STRENGTH	994 psi

APPENDIX C:

ADDITIONAL TESTING OF

SATURATED LIGHTWEIGHT FINE AGGREGATE

Hydrocure

ADDITIONAL TESTING OF LWFA

SAMPLE NUMBER: 12 B ATTEMPT: 1ST
SAMPLE DESCRIPTION: Mn/DOT 3U18 w/ Hydrocure (LWFA)
WATER/CEMENT RATIO: 0.395
DATE MIXED: 2/6/03

BATCH COMPONENTS	DETAILS / SUPPLIER
COARSE AGGREGATE: 73.23 lb	3/8" PEA GRAVEL (WINGRA)
FINE AGGREGATE: 35.78 lb	APPLETON QUARRY
CEMENT: 45.01 lb	TYPE III (LAFARGE)
DESIGN WATER: 17.77 lb	
AIR ENTRAINING ADMIXTURE: 70 mL	DARAVAIR 1400 (GRACE)
OTHER: 35.78 lb	HYDROCURE (17.8% moisture content)

NOTE: At the suggestion of John Roberts (Northeast Solite Corporation/Midwest Lightweight Aggregate Corporation), an additional batch of Sample 12 was mixed with a larger proportion of lightweight fine aggregate (LWFA). For this batch, 50 percent of the sand (fine aggregate) was replaced with LWFA (the replacement in Phase I ranged from 19 to 22 percent, depending on the moisture content of the LWFA). The testing listed below evaluates the effects of a 50 percent replacement of fine aggregate with LWFA (Hydrocure) on the compressive strength and change in height of the patch material.

ADDITIONAL TESTING	RESULTS
CHANGE IN HEIGHT - INITIAL READING	0.3103 in.
1 DAY	0.3115 in., -0.021% change (shrink.)
3 DAYS	0.3118 in., -0.026% change (shrink.)
7 DAYS	0.3113 in., -0.018% change (shrink.)
COMPRESSIVE STRENGTH - 1 DAY	3620 psi
3 DAYS	6440 psi

NOTE: Although this additional testing was conducted too late in the testing process to include this sample in Phase II testing, the patch material mixed with a higher proportion of LWFA showed promising results. This patch material exhibited less shrinkage than the control in the change in height test and the replacement of 50 percent of the sand had very little impact on the compressive strength of the patch material (compared to the compressive strength of the Mn/DOT 3U18 control).